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space station systems analysis study

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(NASA-CR-161927) SPACE STATION SYSTEMS ANALYSIS STUDY. VOLUME 2: PROGRAM OPTIONS, BOOK 1, PARTS 1 AND 2 Final Report (Grumman Aerospace Corp.) 344 p HC A15/MF A01 CSCL 22B G3/18

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FINAL REPORT (PARTS 1 & 2)
Volume 2 Program Options, Book I

25 MARCH 1977

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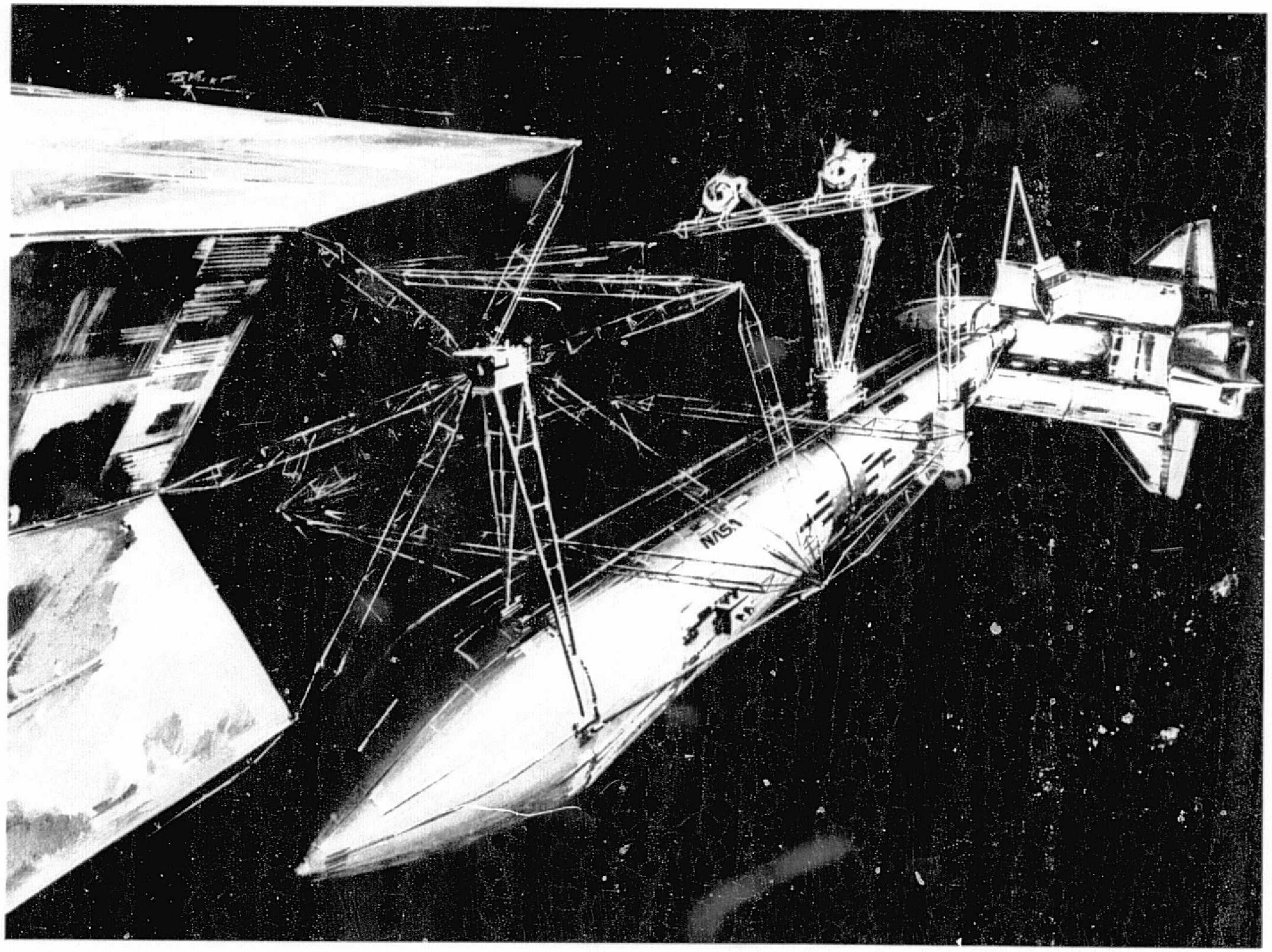
space station systems analysis study



FINAL REPORT (PARTS 1 & 2)

Volume 2 Program Options, Book I

25 MARCH 1977

Report No. NSS-SS-RP014

Contract No. NAS8-31993

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INTRODUCTION

The purpose of the Space Station Systems Analysis Study is to develop and define the elements of Space Station Programs required to support an operational base theme, a space laboratory theme, and advanced missions relatable to public needs/national interests. The study will identify missions satisfying the foregoing requirements, establish program scenarios/options, and define Space Station, transportation system, and mission hardware functional requirements. System options will be defined and evaluated for a selected number of program options. In depth definition, including subsystem analysis and programmatic comparisons, will be performed for selected primary concepts. The net result will be the definition of effective Space Station concepts oriented towards meeting significant national needs and social requirements, and providing economic benefits.

This study is being conducted in three parts running a total of 15 months, with the last month devoted to the Final Report. These parts include:

Part 1 — Define and Evaluate Program Options

Part 2 — Define and Evaluate System Options for Selected Program Options

Part 3 — Refine Selected Program/System Options

Part 1 started on April 1 and was completed on August 20, 1976. Part 2 was initiated on August 21, 1976 and was completed on 11 February, 1977. These study parts have been performed in accordance with the Study Plan, Grumman Report No. NSS-SS-RP001, dated April 16, 1976, and revised on October 15, 1976.

This report, summarizes the results of Parts 1 and 2 and represents the first increment of the study Final Report. It consists of four volumes:

Volume 1 — Executive Summary

Volume 2 — Program Options, Book I

Volume 2 — Program Options, Book II

Volume 3 — Missions, Book I

Volume 3 — Missions, Book II

Volume 4 — Integrated Requirements of Space Construction Base

Subcontractor support for this study has been provided by A. D. Little, Raytheon and Spectrolabs. The Final Report for Part 3 will be delivered at the end of June, 1977.

VOLUME 2 – PROGRAM OPTIONS

PROGRAM OPTIONS
DEFINITION &
INTEGRATED REQUIREMENTS
ROSS FLEISIG

SPACE
CONSTRUCTION
BASE
JOE GOODWIN

CONCEPT DEVELOPMENT
JOE GOODWIN/ROSS FLEISIG

COMPARATIVE EVALUATION
RON MCCAFFREY/JOE GOODWIN

PROGRESSIVE DEVELOPMENT
OPTIONS
RON MCCAFFREY

TRANSPORTATION
RON BOYLAND

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K-316(A)

INTEGRATED SPACE CONSTRUCTION BASE REQUIREMENT DEVELOPMENT

Three sources of data are applied to integrate the crew, mass, volume and electrical power requirements for each Space Construction Base (SCB) program option:

- Program option schedule of milestones, tasks and IOC's
- Current SCB configuration and design
- Mission Requirements Handbook

These integrated data are used in design iteration and preparing the cost and schedules for each option.

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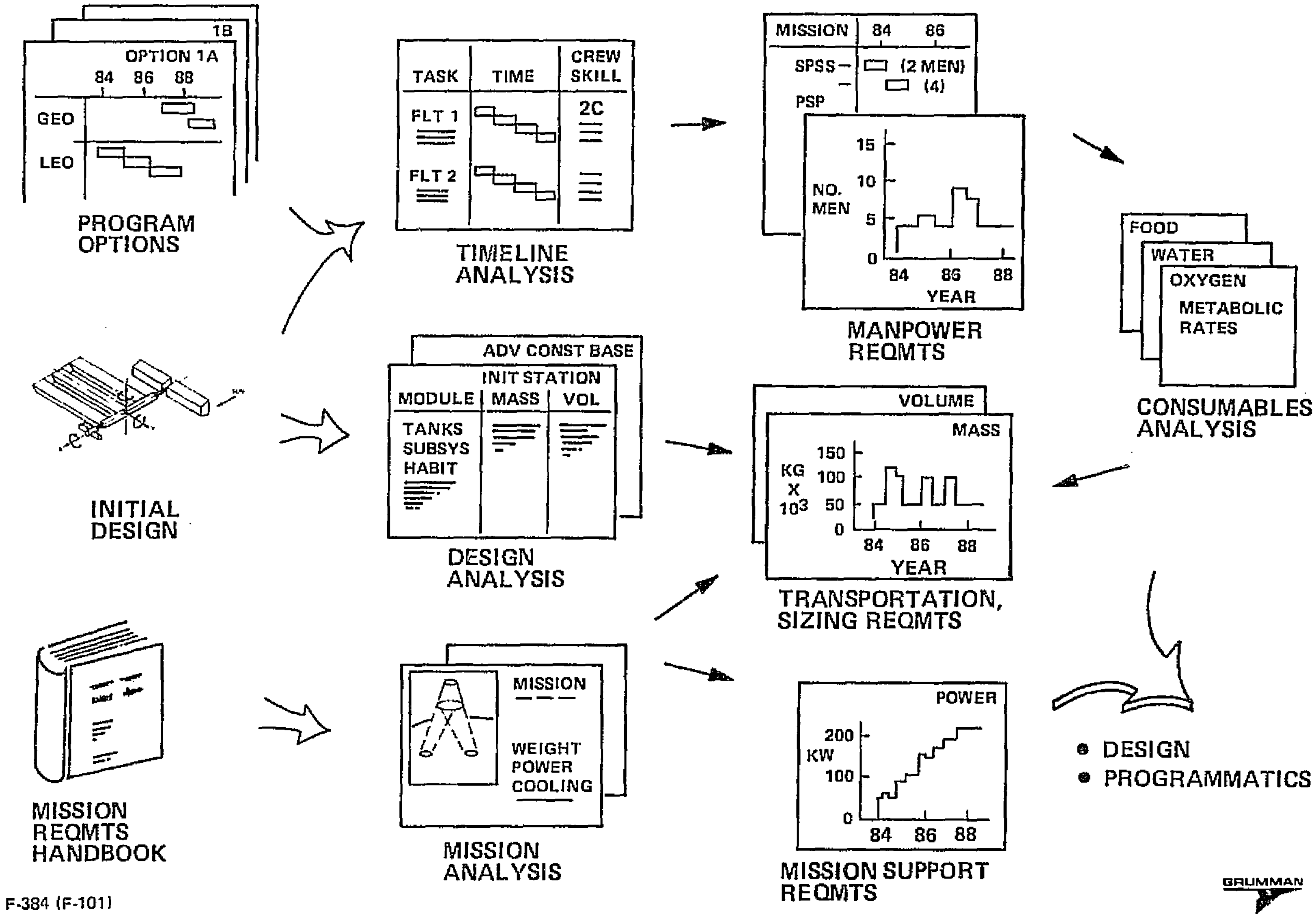
INTEGRATED SPACE CONSTRUCTION BASE REQUIREMENT DEVELOPMENT



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PROGRAM OPTIONS 1A, 1B & 3

This chart defines the program options 1A, 1B and 3 for the 1984 through 1986 time frame. The subsequent chart continues the definition through 1991.

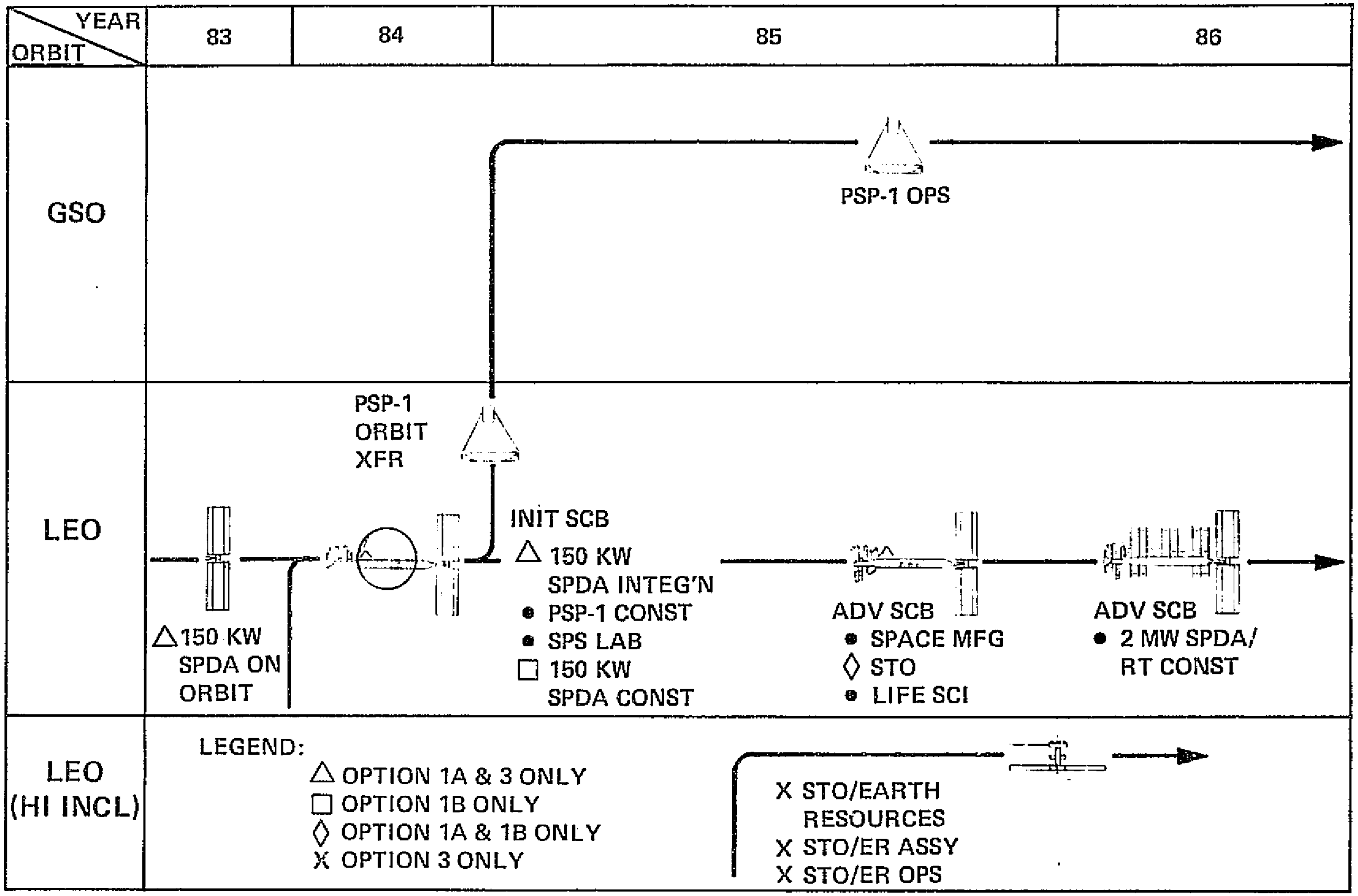
In 1984, Option 1A Initial Space Construction Base (SCB) is assembled in low earth orbit (LEO) and integrated with a 150kw Solar Power Development Article (SPDA) from a prior development program. The first Public Service Platform (PSP-1) is constructed by the SCB, detached and orbited into a geostationary orbit (GSO) where it becomes operational during the first quarter of 1985. While the PSP-1 is being constructed, the Solar Power Station (SPS) lab, which is part of the initial SCB, becomes operational. Early in 1985, the initial SCB is enlarged to an advance SCB configuration and the Space Manufacturing, Solar Terrestrial Observatory (STO) and Life Science (LIFE SCI) activities become operational. The 2mw Solar Power Development Article/Radio Telescope (SPDA/RT) is constructed by the advanced SCB during the second quarter of 1986. It is detached from the SCB and remains in LEO for further tests.

Option 1B definition is similar to Option 1A except for the 150kw SPDA LEO activity in 1984. In Option 1B, the 150kw SPDA is not available from a prior development program and is thus constructed by the initial SCB.

In Option 3, the STO activity is deleted from LEO/28.5 deg and added to LEO high inclination (Hi-Incl). The Solar Terrestrial Observatory/Earth Resources (STO/ER) lab is launched directly from the ground into a LEO Hi-Incl orbit during late 1985. The Earth Resources PSP (part of the STO/ER) is assembled and becomes operational along with the STO early in 1986.

F-382T

PROGRAM OPTION 1A, 1B & 3 (SHEET 1 OF 2)



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F-382

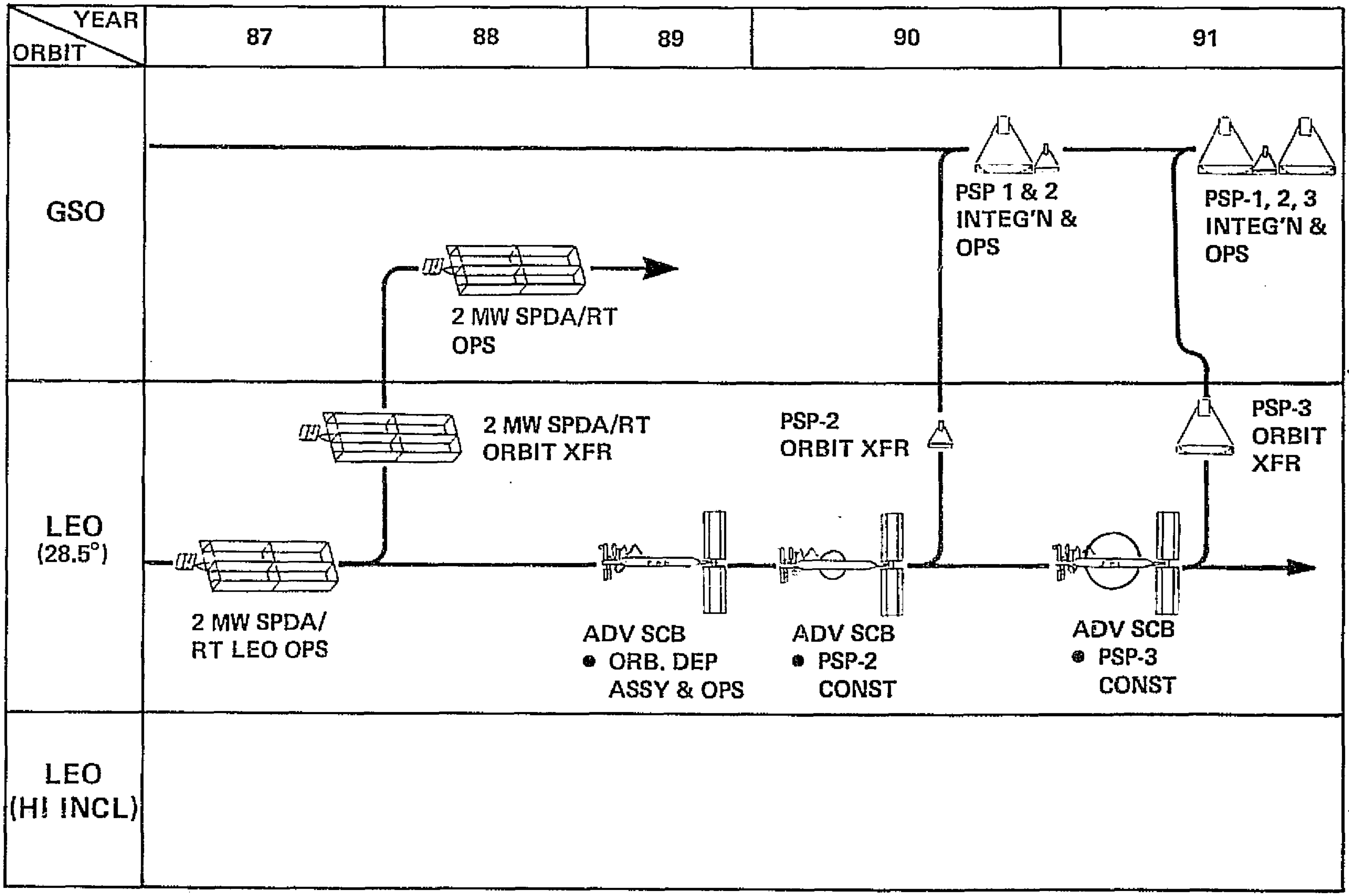
PROGRAM OPTIONS 1A, 1B & 3 (Cont.)

This chart continues the definition of options 1A, 1B and 3 from the previous chart through the year 1991. It is during this time frame that the Orbital Depot (ORB DEP) becomes operational and supports the Orbit Transfer Vehicle (OTV) which becomes the main carrier for transporting mission hardware between orbits.

The detached 2mw SPDA/RT remains in LEO throughout 1987 and is subsequently orbited into GSO by an Interim Upper Stage/Solar Electric Propulsion System (IUS/SEPS) combination; the GSO 2mw SPDA/RT becomes operational during 1988. In 1989, the LEO advanced SCB assembles, checks out and places into service the ORB DEP. After the ORB DEP assembly is completed, the second Public Service Platform (PSP-2) is constructed by the LEO advanced SCB, detached and placed into GSO by an OTV. There, PSP-2 is integrated with PSP-1, which was orbited into GSO in 1985. The combined GSO PSPs become operational in 1990. The third PSP is constructed, transported and integrated in an identical manner as the second PSP. The combined GSO PSPs, i.e. PSP-1, 2 and 3, become operational in 1991.

F-383T

PROGRAM OPTION 1A, 1B & 3 (SHEET 2 OF 2)



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PROGRAM OPTION 2A

This chart defines the program Option 2A for the time frame from 1984 to mid-1986. The subsequent chart continues the definition through the year 1991. The one activity which distinguishes this option from all other options is the construction of large structures, e.g., the 2mw SPDA/RT, in geostationary orbit.

The early stages of this option are similar to Option 1A. In 1984, the Option 2A initial SCB is assembled in LEO from modules launched from the ground and integrated with a 150kw SPDA left in orbit from a prior development program. The first PSP is then constructed with the assembled SCB, detached and orbited into a geostationary orbit where PSP-1 becomes operational during the first quarter of 1985. While the PSP-1 is being constructed, the SPS lab becomes operational. At this time, Option 2A departs from the Option 1A scenario. The initial SCB is enlarged to an advance SCB configuration in 1985 and the Space Manufacturing activity aboard the advance SCB becomes operational. The GSO SCB is assembled and left in LEO while the advance SCB assembles, checks out and places into service the ORB DEP. The OTV, serviced by the ORB DEP, then transports the GSO SCB to a geostationary orbit where construction of the 2mw SPDA/RT takes place during the early part of 1986. While the ORB DEP is being assembled, the LIFE SCI activity aboard the LEO advance SCB becomes operational.

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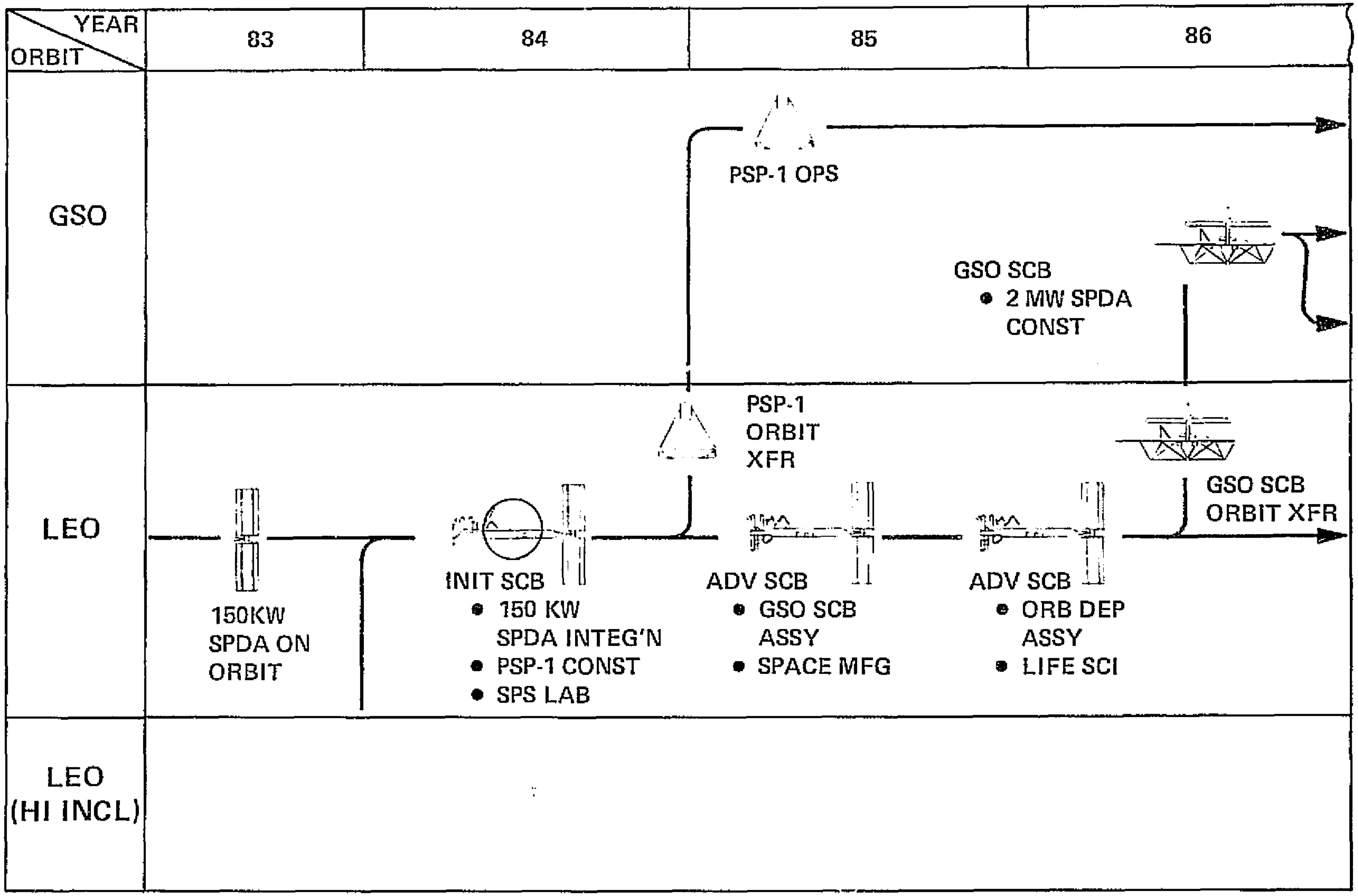
PROGRAM OPTION 2A (SHEET 1 OF 2)



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PROGRAM OPTION 2A (CONT)

This chart continues the definition of the Option 2A from the previous chart through the year 1991. Option 2A differs from Option 1A in the construction of large structures, such as the Public Service Platforms, in geostationary orbit.

It is seen from the previous chart that the GSO SCB constructed the 2mw SPDA/RT in early 1986. After construction and checkout, the 2mw SPDA/RT is detached from the SCB and is placed in service in mid-1986. It is at this time the STO lab aboard the GSO SCB becomes operational. The second Public Service Platform is constructed by the GSO SCB, detached from the base and integrated with PSP-1 which was orbited from LEO into geostationary orbit in 1985. The combined GSO PSPs are pressed into service in early 1987. The third PSP is constructed, detached and integrated in an identical manner as the second PSP. The combined GSO PSP's, i.e. PSP-1, 2 and 3, are pressed into service during the latter part of 1987. The last activity the GSO SCB performs during this time frame is construction of the Navigation and Surveillance Public Service Platform (N&S PSP).

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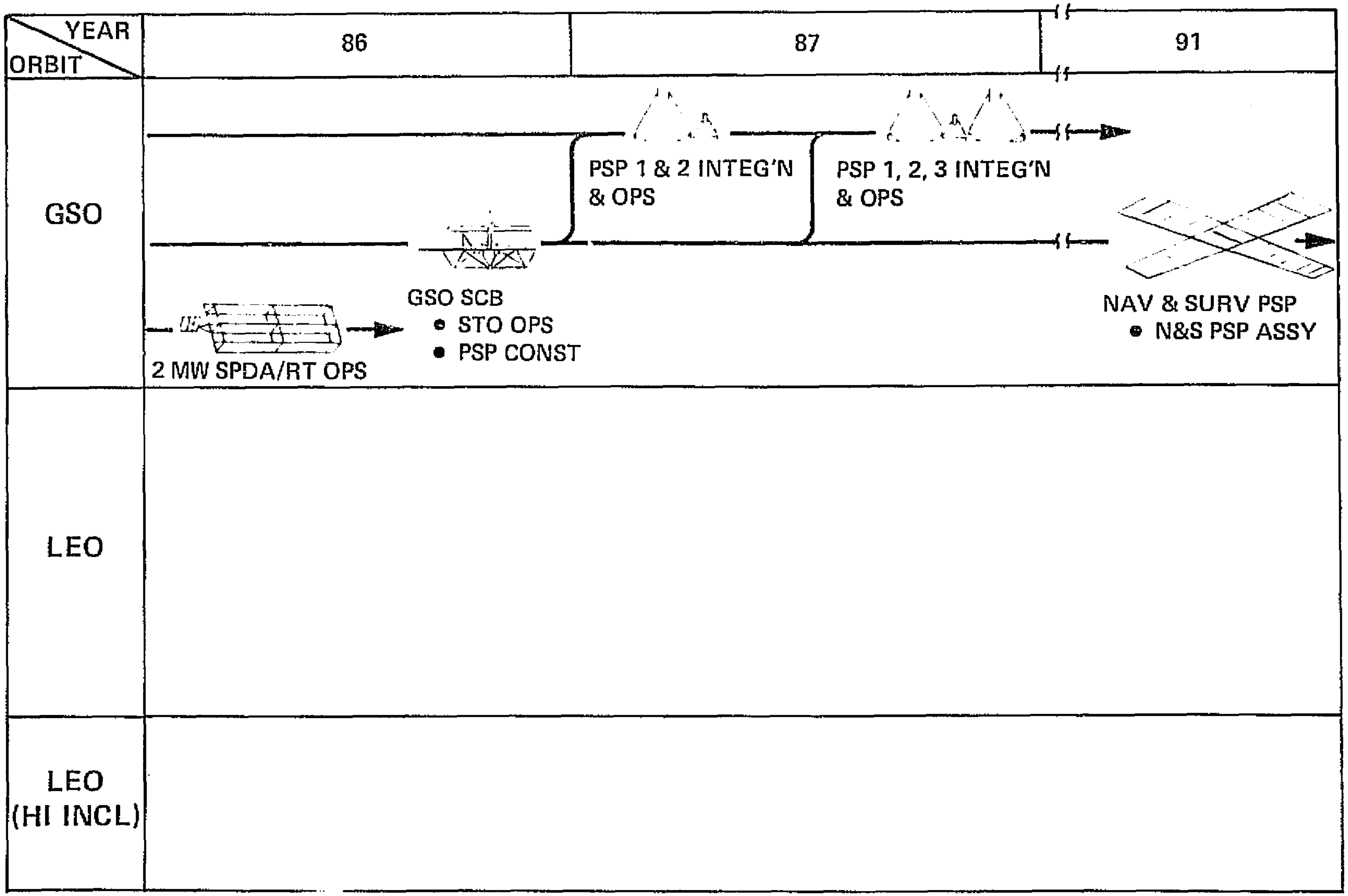
PROGRAM OPTION 2A (SHEET 2 OF 2)



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PROGRAM OPTION 2B

This chart defines the program Option 2B for the time frame from 1984 to mid-1986. The subsequent two charts continue the definition through the year 1991. The time-phased activities defined for Option 2B in this chart are identical to Option 1A. The differences between options begin in mid-1986.

In 1984, the Option 2B initial SCB is assembled in LEO from modules launched from the ground and integrated with a 150kw SPDA left in orbit from a prior development program. The first PSP is then constructed with the assembled SCB, detached and orbited into a geostationary orbit where it becomes operational during the first quarter of 1985. While the PSP-1 is being constructed, the SPS lab aboard the initial SCB becomes operational. Early in 1985, the initial SCB is enlarged to an advance SCB configuration and the Space Manufacturing, Solar Terrestrial Observatory (STO) and Life Science (LIFE SCI) activities aboard the LEO advance SCB become operational. The 2mw SPDA/RT is constructed by the advance SCB early in 1986.

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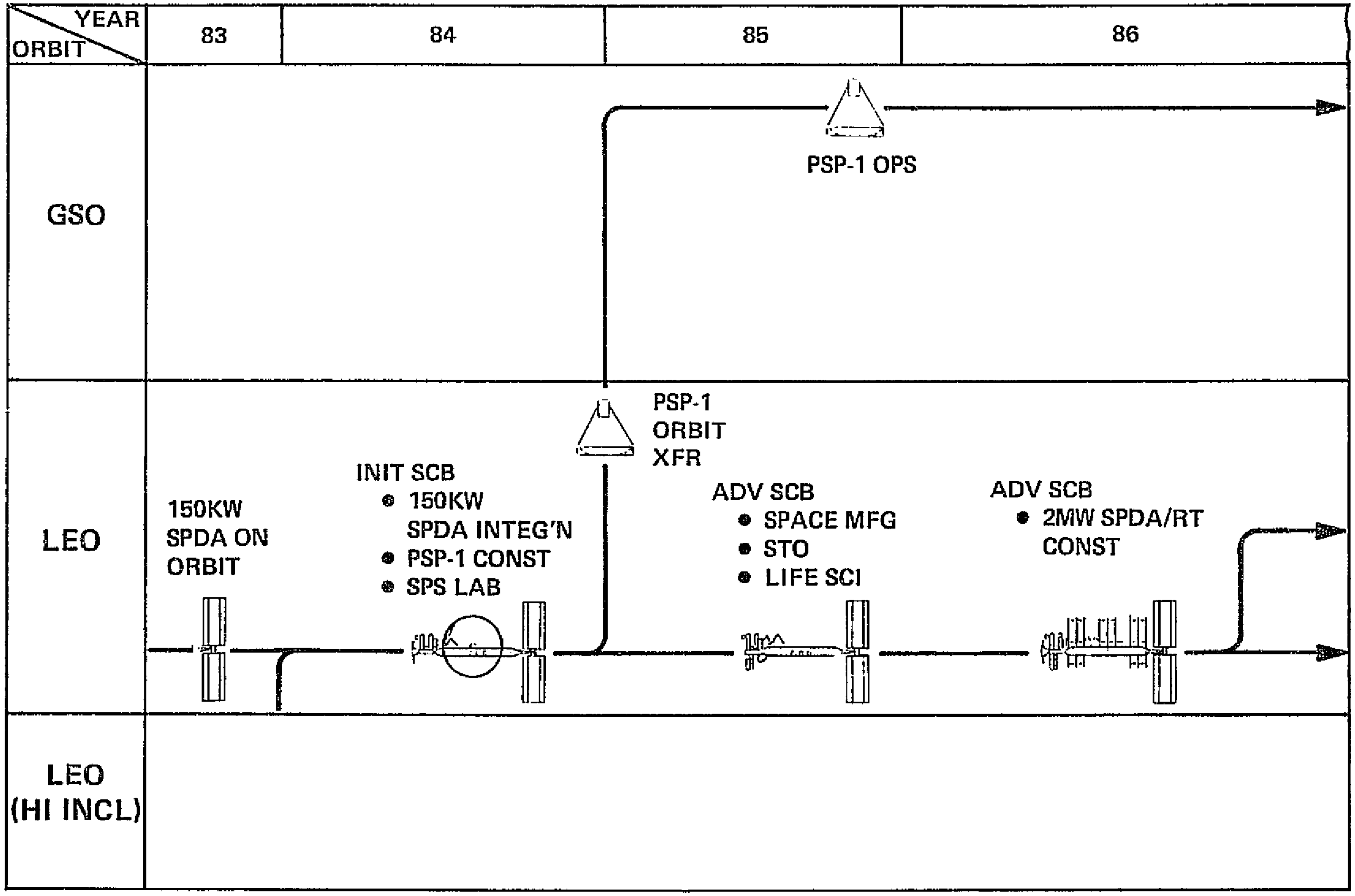
PROGRAM OPTION 2B (SHEET 1 OF 3)



PROGRAM OPTION 2B (CONT)

This chart continues the definition of the Option 2B from the previous chart through the year 1988. The activity which distinguishes this option from other options is the placement of a GSO Demonstration Base (GSO DEMO BASE) into a geostationary orbit from LEO. This base allows frequent GSO sortie flights in which the crew performs part-time STO experiments and demonstrates man's ability to perform tasks in a geostationary orbit. This base is the forerunner of a Space Operations Base (SPACE OPS BASE) which is described in the subsequent chart.

It is seen from the previous chart that the LEO advance SCB constructed the 2mw SPDA/RT in early 1986. After construction and checkout, the 2mw SPDA/RT is detached from the SCB and is placed in service in early 1986 through 1987. It is during this time frame that the LEO advance SCB assembles the GSO DEMO BASE and the ORB DEP. The OTV, serviced by the ORB DEP, then transports the GSO DEMO BASE to a geostationary orbit. The GSO DEMO BASE contains a partial complement of STO equipment and the necessary equipment for man to demonstrate his ability to perform geostationary activities. In the early part of 1988, the OTV transports the 2mw SPDA/RT from LEO into a geostationary orbit. After the ORB DEP assembly is completed and in service, the second PSP is constructed by the LEO advance SCB, detached and placed into GSO by the OTV in the second quarter of 1988. There PSP-2 is integrated with PSP-1 which was orbited into GSO in 1985. The combined GSO PSPs become operational in 1988.

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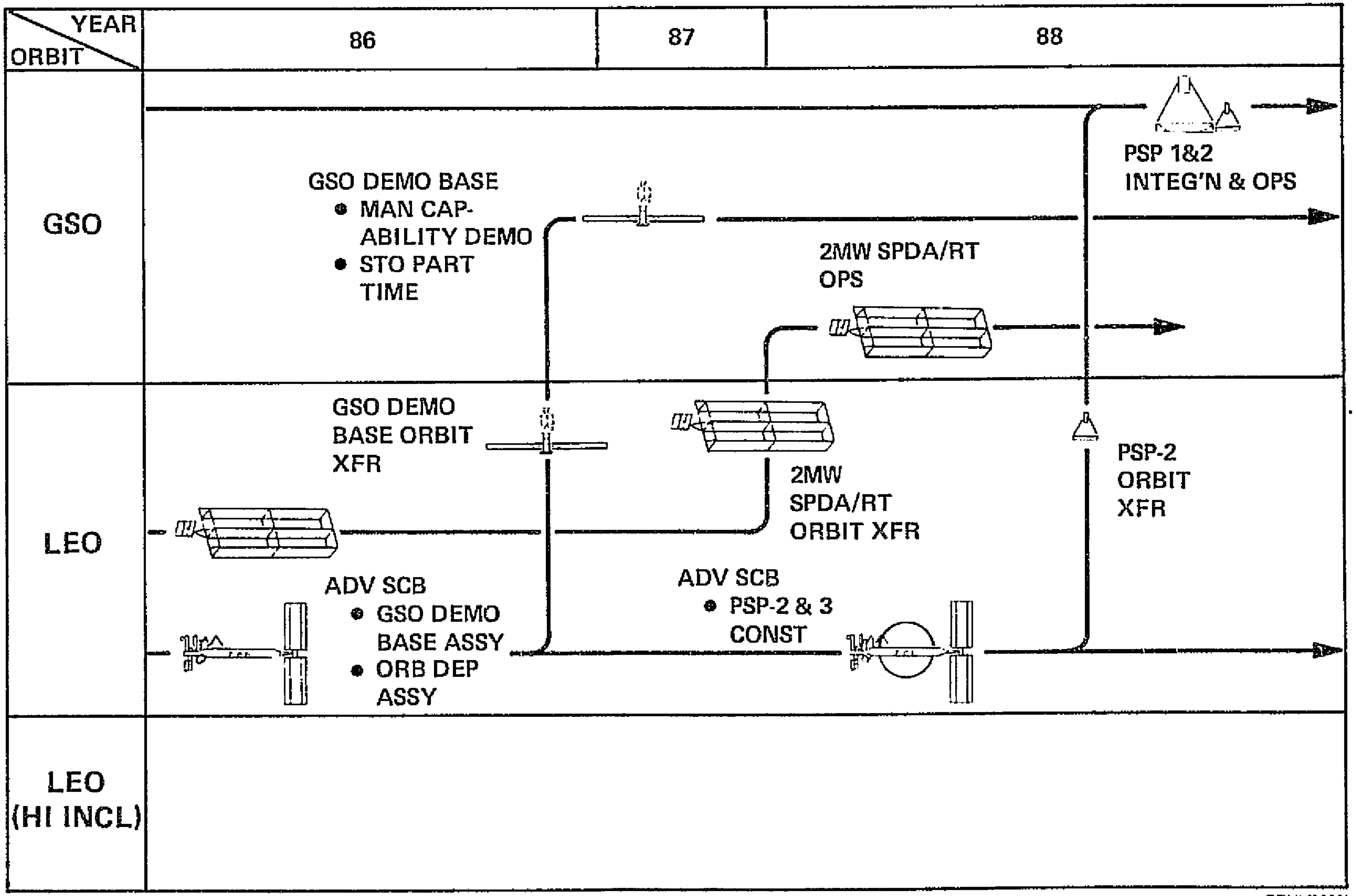
PROGRAM OPTION 2B (SHEET 2 OF 3)



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PROGRAM OPTION 2B (CONT)

This continues the definition of the Option 2B from the previous chart thru the year 1991. The activity which distinguishes this option from other options is the growth of the GSO DEMO BASE into a Space Operations Base (SPACE OPS BASE). The SPACE OPS BASE houses a permanant crew, a full complement of STO experiments and the necessary equipment to assemble the N&S PSP.

The previous chart shows that the second PSP was constructed by the LEO advance SCB, detached, transported into a geostationary orbit by the OTV and integrated with the PSP-1. The combined GSO PSP's become operational in 1988. Early in 1989, the third PSP is constructed, detached, transported and integrated in the same manner as the second PSP. The combined GSO PSP's, i.e., PSP-1, 2 and 3, are pressed into service during early 1989. The SPACE OPS BASE is assembled by the LEO advance SCB and is transported to a geostationary orbit by the OTV. There the SPACE OPS BASE is integrated with the GSO DEMO BASE. The SPACE OPS BASE, with its permanent crew and full complement of STO experiments, becomes operational in 1989. The last activity the SPACE OPS BASE performs during this time frame is construction of the N&S PSP. This occurs in 1991.

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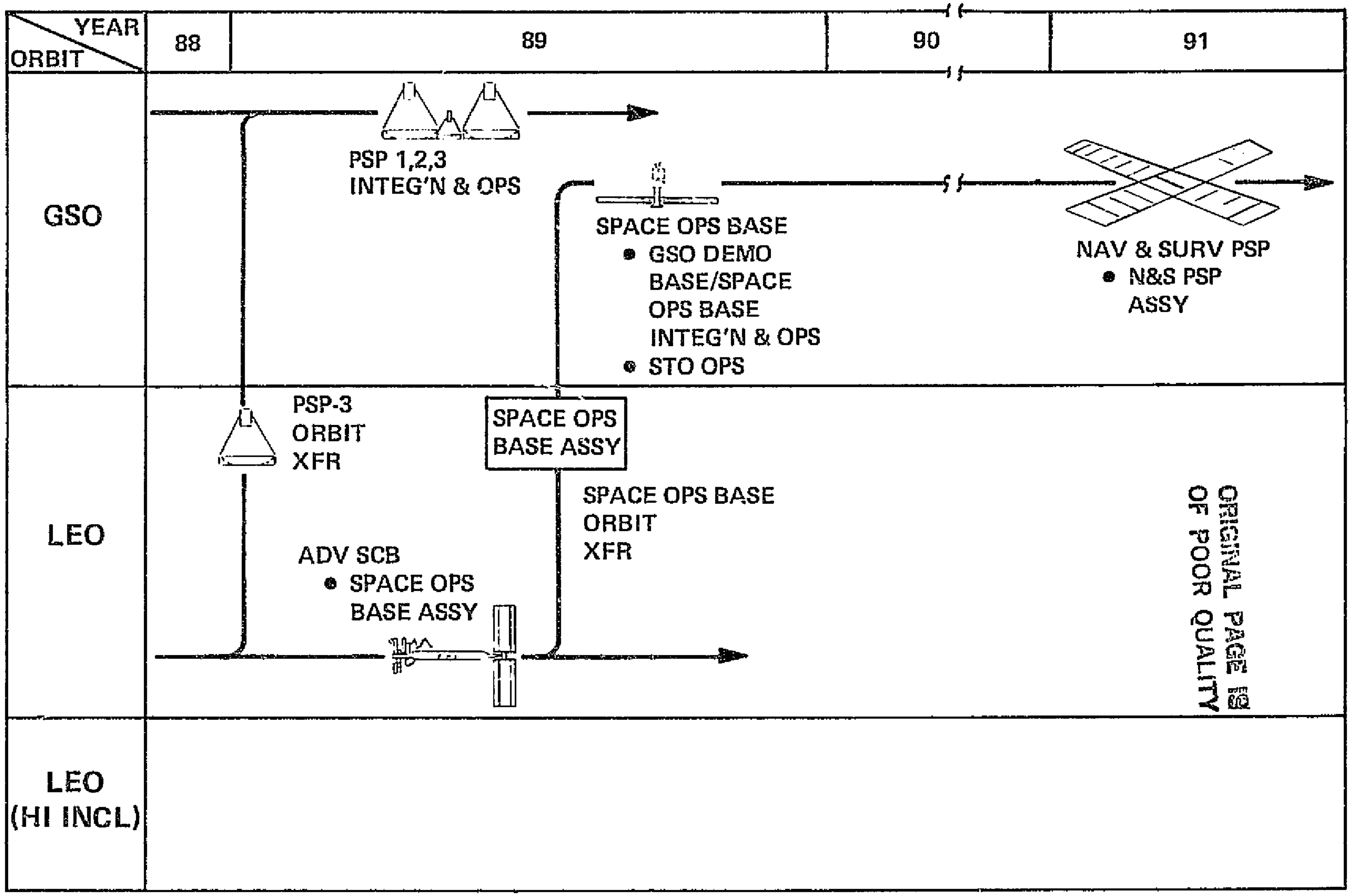
PROGRAM OPTION 2B (SHEET 3 OF 3)



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INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER OPTION 1A – LEO

These graphs summarize the integrated SCB requirements for the time period 1984 through 1991. These requirements are for use in determining transportation requirements, design modifications and program costs.

The requirements for this and subsequent charts are based on the program options described earlier in this section and on the following ground rules:

- Nominally one shuttle flight/month – 2 flights/month max
- Single shift crew/10 hr max workday
- Six hour EVA daily maximum/person
- Shuttle provides manned and logistics support prior to habitation module assembly to the SCB
- OTV provides support and habitation during combined PSP assembly and 2 mw SPDA/RT servicing in GSO.

In general, the requirement levels remain constant except during SCB build-up and construction operations. The major drivers contributing to the peaks during the two operations above are as follows:

- 1984 – LEO initial SCB build-up, PSP-1 construction
- 1985 – LEO advance SCB build-up
- 1986 – 2 mw SPDA/RT build-up
- 1989 – Orbital Depot build-up
- 1990 – PSP-2 construction
- 1991 – PSP-3 construction.

A majority of the crew for the Flight Operations and Other category is required to operate the various laboratories which include SPS, STO and LIFE SCI activities.

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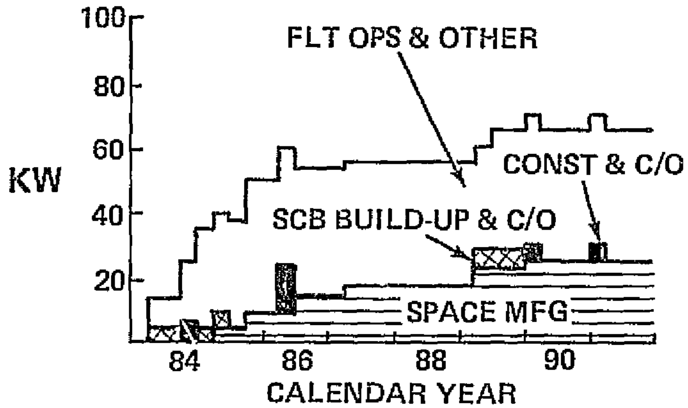
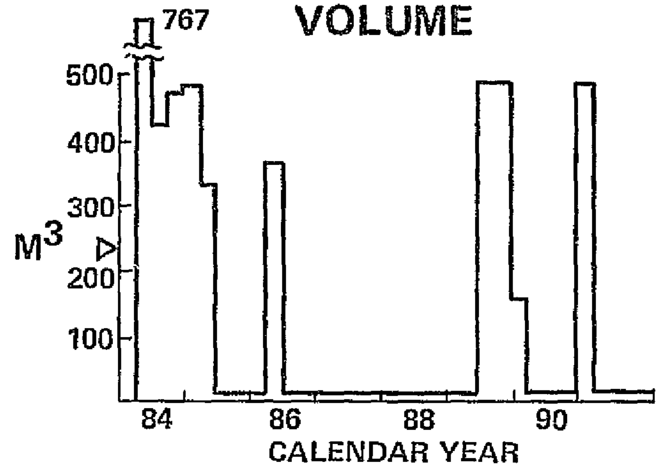
INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR

OPTION 1A – LEO

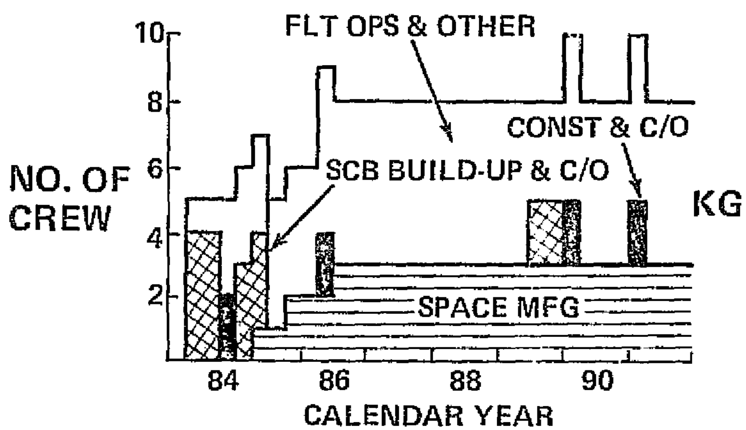
ELECTRIC POWER



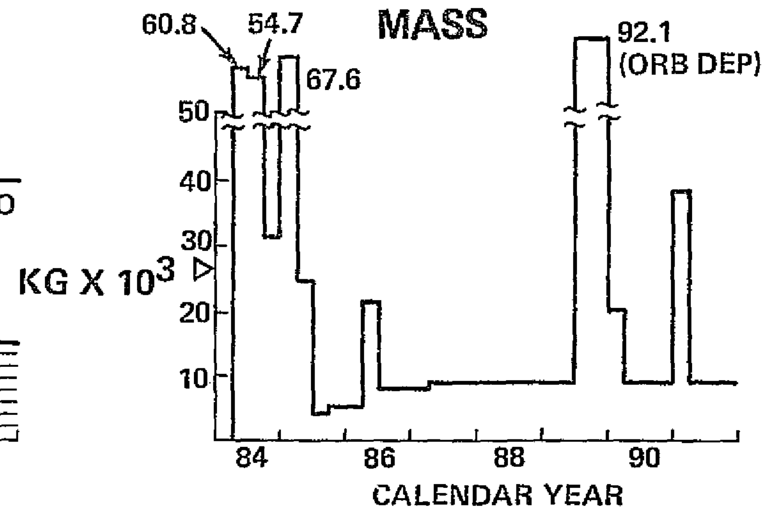
VOLUME



NO. OF CREW



MASS



▷ SHUTTLE CAPABILITY

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INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR OPTION 1A-GSO

These graphs summarize the integrated SCB requirements for the time period 1984 through 1991. The data are used to determine transportation requirements, design modifications and program costs.

This program option is characterized by GSO sortie flights which provide the necessary support (crew and electrical power) to (1) integrate and service the three PSP antennas and (2) service the 2mw SPDA/RT. A two-man servicing crew is required for each GSO sortie flight; the required 5 kw electrical power is supplied by the servicing OTV and/or the equipment being serviced. The PSP-1 and 2 mw SPDA/RT are transferred from LEO to geostationary orbit by an IUS/SEPS combination vehicle; PSP-2 and -3 are transferred via the OTV.

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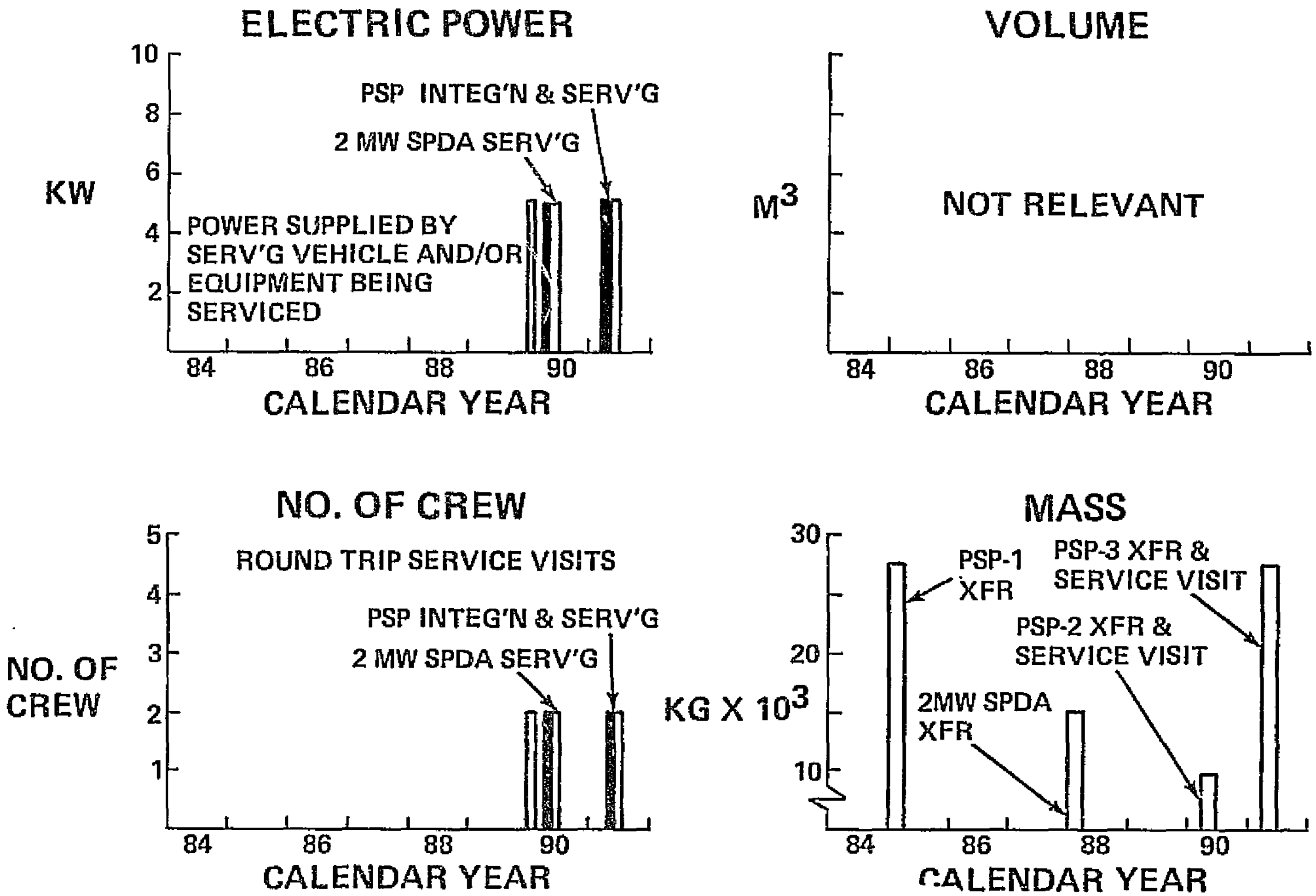
INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR

OPTION 1A – GSO



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INTEGRATED SCB REQUIREMENTS IN ORBIT
BY QUARTER YEAR
OPTION 1B-LEO

The graphs on this chart summarize the integrated SCB requirements for Option 2B for the time period 1984 through 1991. The requirements are used to determine transportation requirements, design modifications and program costs.

Manpower requirements (NO. OF CREW) peak at 10 men in 1990. The average manpower requirements for the initial SCB is five men; for the advance SCB, it is eight men. An average of five men is required for the FLT OPS & OTHER category. Of the five men, three are required to man the SPS, STO and LIFE SCI labs. The PSP and 2mw SPDA/RT construction and C/O tasks never require more than two men. The ramps which appear on the Space Manufacturing curve are a function of when the biological, solidification and crystal branch modules come on line. Two men who are borrowed from the FLT OPS & OTHER category are required to assemble the ORB DEP in 1989.

Electrical power requirements peak at approximately 70 kw in 1990. The peak electrical power requirements for the initial SCB is approximately 35 kw of which 11 kw is required to construct the 150 kw SPDA. The average electrical power for the initial base runs about 20 kw. With respect to the advance SCB, the average electrical power runs about 55 kw up to 1989; after 1989 the average electrical power runs about 65 kw. The jump in electrical power average is attributed to increased Space Manufacturing activity. The PSP construction during 1984, 1990 and 1991 require approximately 7 kw. The 150 kw SPDA and the 2mw SPDA/RT require about 11 kw during SCB BUILD-UP & C/O and CONST & C/O activities in 1984 and 1986 respectively. The SPACE MFG ramps are a function of increased activities.

The major drivers contributing to the peaks appearing on the MASS and VOLUME curves and to a lesser extent on the NO. OF CREW and ELECTRIC POWER are as follows:

- 1984 — LEO initial SCB build-up, 150 kw SPDA and PSP-1 construction
- 1985 — LEO advance SCB build-up
- 1986 — 2mw SPDA/RT construction
- 1989 — ORB DEP build-up
- 1990 — PSP-2 construction
- 1991 — PSP-1 construction.

Approximately 8000 kilograms of mass and 8 m^3 of volume are required per quarter from 1984 through 1991 for crew rotation, expendable, RCS propellant, space manufacturing materials and spares.

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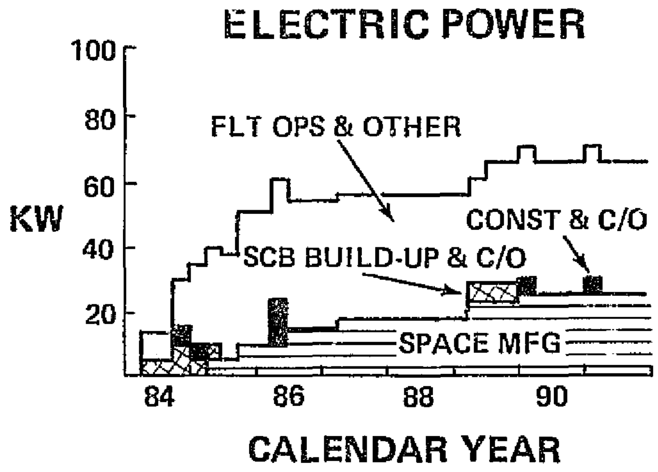
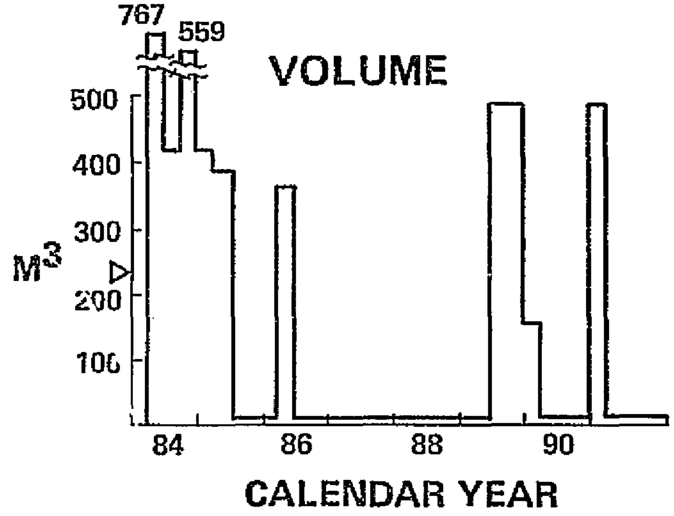
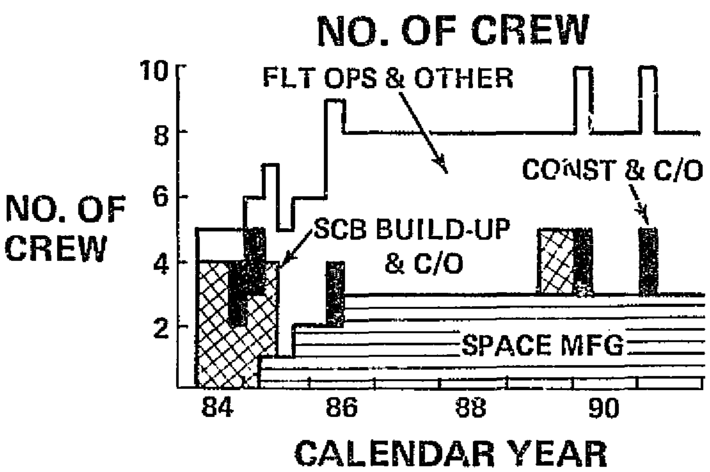
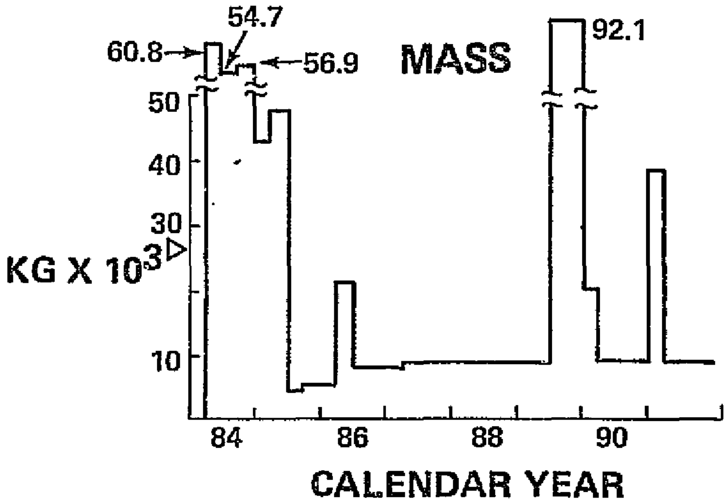
INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR

OPTION 1B – LEO









▷ SHUTTLE CAPABILITY

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INTEGRATED SCB REQUIREMENTS IN ORBIT
BY QUARTER YEAR
OPTION 1B-GSO

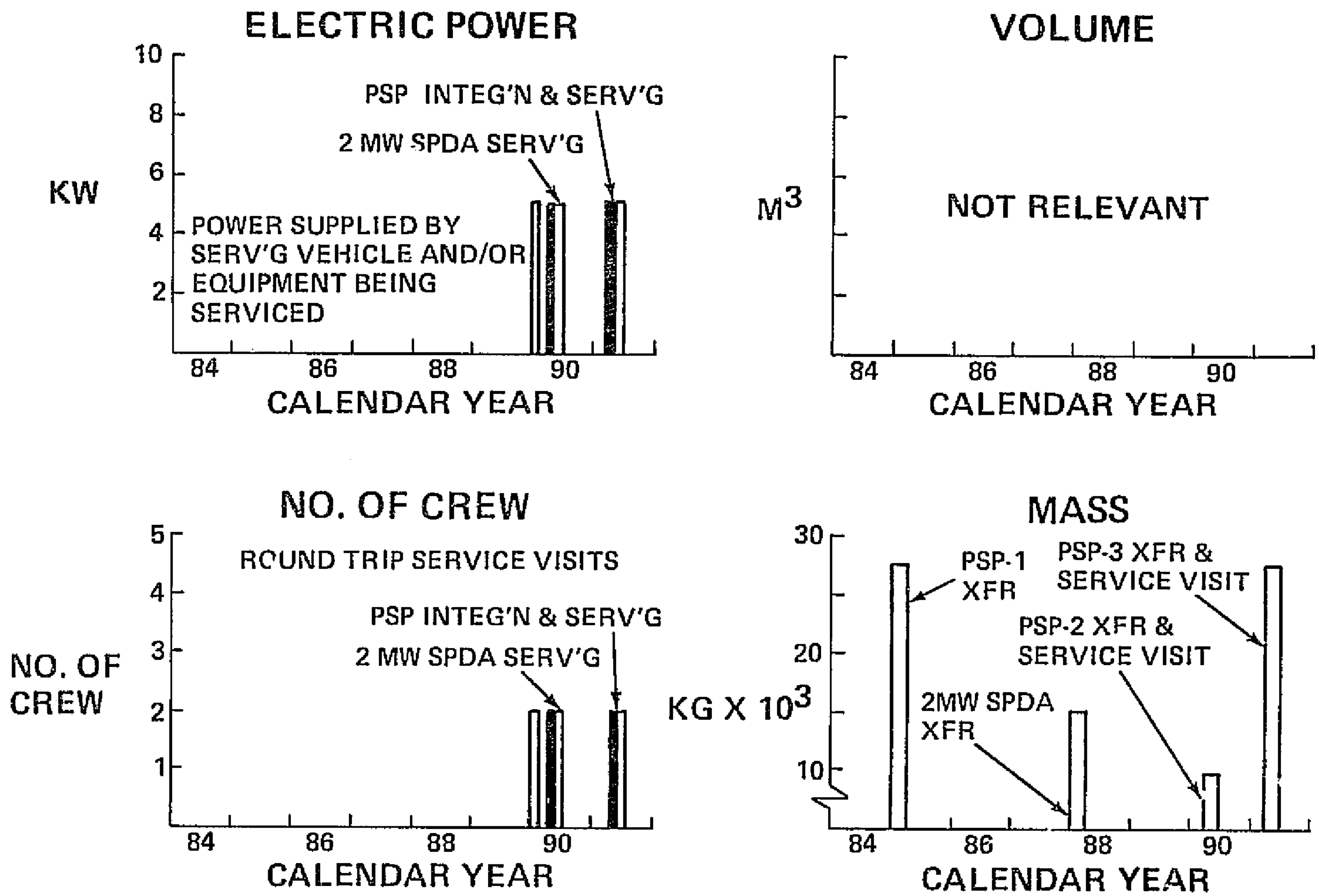
These graphs summarize the integrated SCB requirements for the time period 1984 through 1991. The data are used to determine transportation requirements,design modifications and program costs. program costs.

This program option is characterized by GSO sortie flights which provide the necessary support (crew and electrical power) to (1) integrate and service the three PSP antennas and (2) service the 2mw SPDA/RT. A two-man servicing crew is required for each GSO sortie flight; the required 5 kw electrical power is supplied by the servicing OTV and/or the equipment being serviced. The PSP-1 and the 2mw SPDA/RT are transferred from LEO to geostationary orbit by an IUS/SEPS combination vehicle; PSP-2 and -3 are transferred via the OTV.

F-357T

INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR

OPTION 1B – GSO



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INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR OPTION 2A-LEO

The graphs on this chart summarize the integrated SCB requirements for Option 2A for the time period between 1984 through 1991. The requirements are used to determine transportation requirements, design modifications and program costs.

Manpower requirements (NO. OF CREW) peak at eight men in mid-1986 and remain at that level through 1991. The average manpower requirements for the initial SCB is five men; for the advance SCB, it is eight men. The crew requirement for the FLT OPS & OTHER category build up to five men during the second quarter of 1986 and remain constant through 1991. Of the five men, three are required to man the SPS and LIFE SCI labs. The PSP-1 construction in 1984 requires two men. The ramps which appear on the SPACE MFG curve are a function of when the biological, solidification and crystal branch modules come on line. Two men who are borrowed from the FLT OPS & OTHER category during the fourth quarter of 1985 and the first quarter of 1986, are required to assemble the ORB DEP.

Electrical power requirements peak at approximately 60 kw in 1990. The peak electrical power requirements for the initial SCB is approximately 25 kw of which 18 kw is attributed to the FLT OPS & OTHER category and 7 kw to PSP-1 construction. Of the 18 kw attributed to FLT OPS & OTHER, 10 kw are required for the SPS lab. With respect to the advance SCB, the electrical power builds up to the peak value of 60 kw in 1990 and thereafter remains constant. The ramps in the electrical power profile after the SCB BUILD-UP & C/Oand CONST & C/O are completed, are attributed to increase SPACE MFG activity for which ramps are described above.

The major drivers contributing to the peaks appearing on the MASS and VOLUME curves and to a lesser extent on the NO. OF CREW and ELECTRIC POWER are as follows:

- 1984 – LEO initial SCB build-up, PSP-1 construction
- 1985 – LEO advance SCB, GSO SCB and ORB DEP build-up
- 1986 – ORB DEP build-up, 2mw SPDA/RT and PSP-2 construction material for orbit transfer from LEO to GSO
- 1987 – PSP-3 construction material for orbit transfer.

Approximately 8000 kilograms of mass and 8 m^3 of volume are required per quarter from 1984 through 1991 for crew rotation, expendables, RCS propellant, space manufacturing materials and spares.

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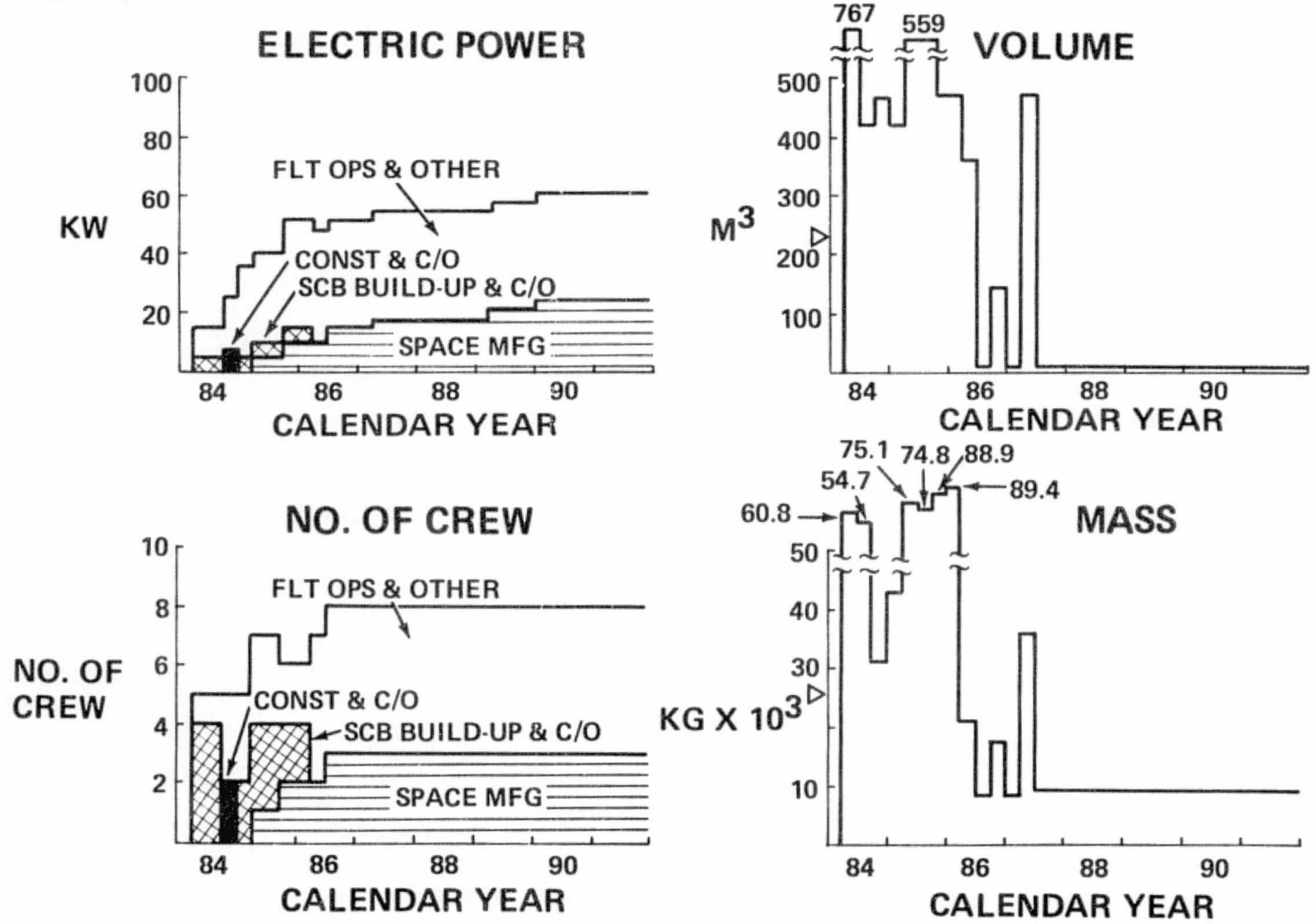
INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR

OPTION 2A – LEO



▷SHUTTLE CAPABILITY

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INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR OPTION 2A – GSO

These graphs summarize the integrated SCB requirements for the time period 1984 through 1991. The data are used to determine transportation requirements, design modifications and program costs.

This program option is characterized by a GSO SCB which constructs PSP, 2 mw SPDA/RT and a Navigation and Surveillance antenna. A three-man crew mans the GSO SCB. They are scheduled to share their time among construction, STO and flight operation activities.

Electrical power requirements peak at approximately 35 kw in 1986. The valleys in the electrical power during a construction task result from shutting down the manned portion of the STO activity, since these men are needed for constructing the PSP, 2 mw SPDA/RT or the NAV & SURV antenna. Approximately 13 kw are required for the STO operation.

The major drivers contributing to the peaks appearing on the mass curve are as follows:

- 1985 – PSP-1 orbit transfer from LEO to geostationary
- 1986 – GSO SCB orbit transfer from LEO to GSO, 2 mw SPDA/RT and PSP-2 assembly
- 1987 – PSP-3 assembly.
- 1991 – NAV & SURV ANT assembly

Approximately 1.6 kilograms of mass are required per quarter from 1984 through 1991 for crew rotation, expendables, RCS propellant and spares.

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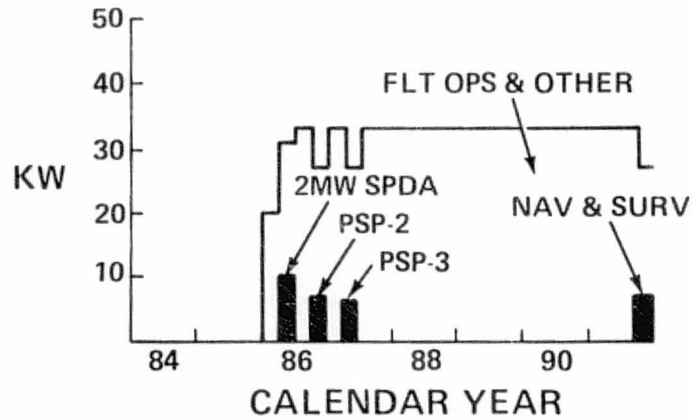
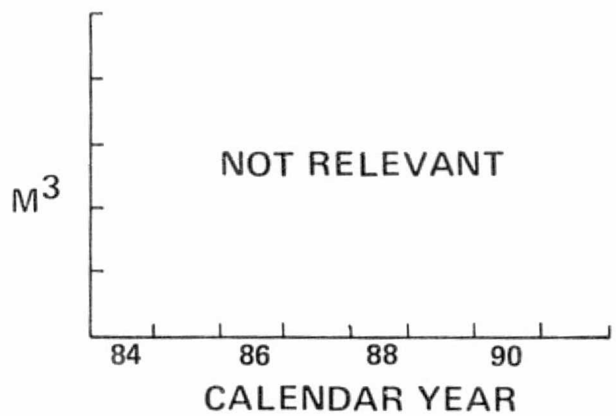
INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR
OPTION 2A – GSO

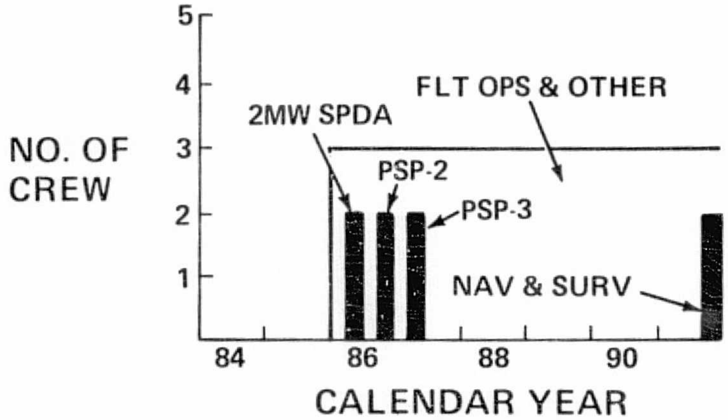
ELECTRIC POWER

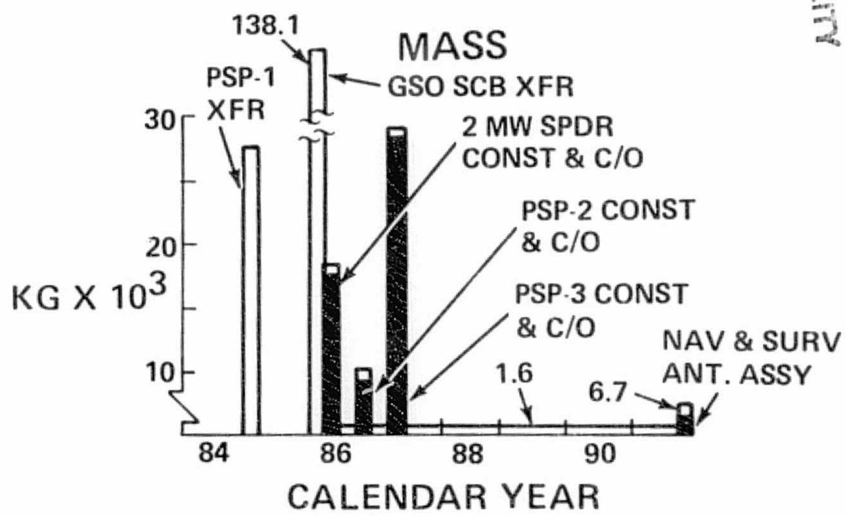


VOLUME



NO. OF CREW





INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR OPTION 2B-LEO

The graphs on this chart summarize the integrated SCB requirements for Option 2B for the time period 1984 through 1991. The requirements are used to determine transportation requirements, design modifications and program costs.

Manpower requirements (NO. OF CREW) peak at 11 men during assembly of the SPACE OPS BASE in 1989 and 1990. The average manpower requirements for the initial SCB is five men; for the advance SCB, it is eight men. The crew for the FLT OPS & OTHER category builds up to five men in 1986 and remains constant through 1991. Of the five men, three are required to man the SPS, STO and LIFE SCI labs. The PSP and 2mw SPDA/RT CONST & C/O tasks require two men for each activity. The ramps which appear on the SPACE MFG curve are a function of when the biological, solidification and crystal branch modules come on line. Two men are borrowed from the FLT OPS & OTHER category to assemble the ORB DEP in 1986.

Electrical power requirements peak at approximately 70 kw in 1990. The peak electrical power requirements for the initial SCB is approximately 25 kw of which 18 kw are attributed to the the FLT OPS & OTHER category and 7 kw to PSP-1 construction. Of the 18 kw attributed to FLT OPS & OTHER, 10 kw are required for the SPS lab. With regards to the advance SCB, the electrical power builds up to a 70 kw peak in the first quarter of 1990, drops to 63 kw in the second quarter and thereafter remains constant. The PSP construction during 1984, 1988 and 1989 require approximately 7 kw. The 2 mw SPDA/RT construction in 1986 requires approximately 11 kw. The SCB BUILD-UP activities, i.e., initial and advance SCB assembly, Orbital Depot assembly, GSO Demonstration Base assembly and the Space Operations Base assembly, require approximately 5 kw.

The major drivers contributing to the peaks appearing on the MASS and VOLUME curves, and to a lesser extent on the NO. OF CREW and ELECTRIC POWER are as follows:

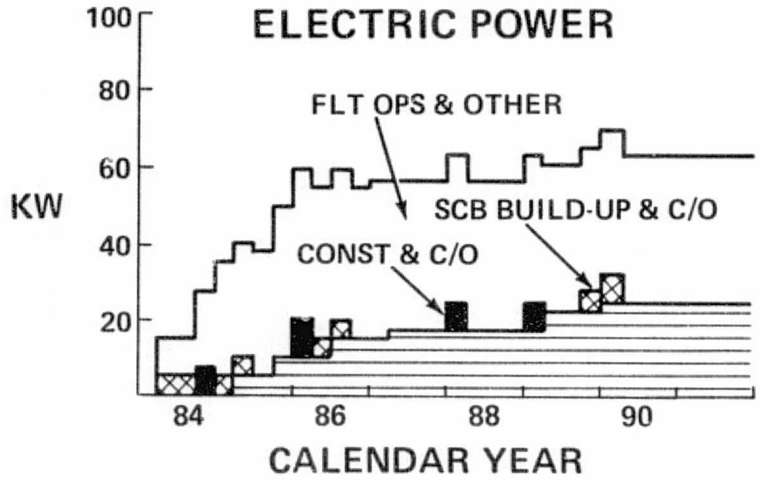
- 1984 – LEO initial SCB build-up, PSP-1 construction
- 1985 – LEO advance SCB build-up
- 1986 – 2mw SPDA/RT construction, Orbital Depot and GSO Demonstration Base build-up
- 1988 – PSP-2 construction
- 1989 – PSP-3 construction, Space Operations Base build-up.

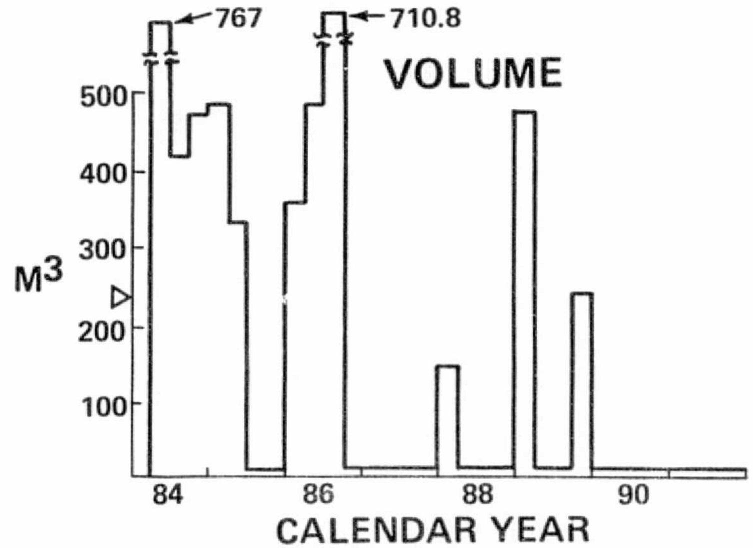
Approximately 8000 kilograms of mass and 8 m^3 of volume are required per quarter from 1984 through 1991 for crew rotation, expendables, RCS propellant, space manufacturing materials and spares.

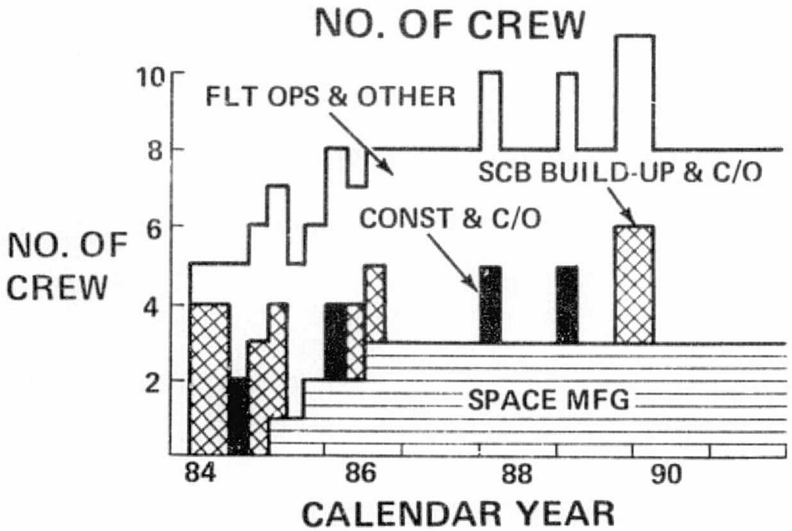
F-360T(1)

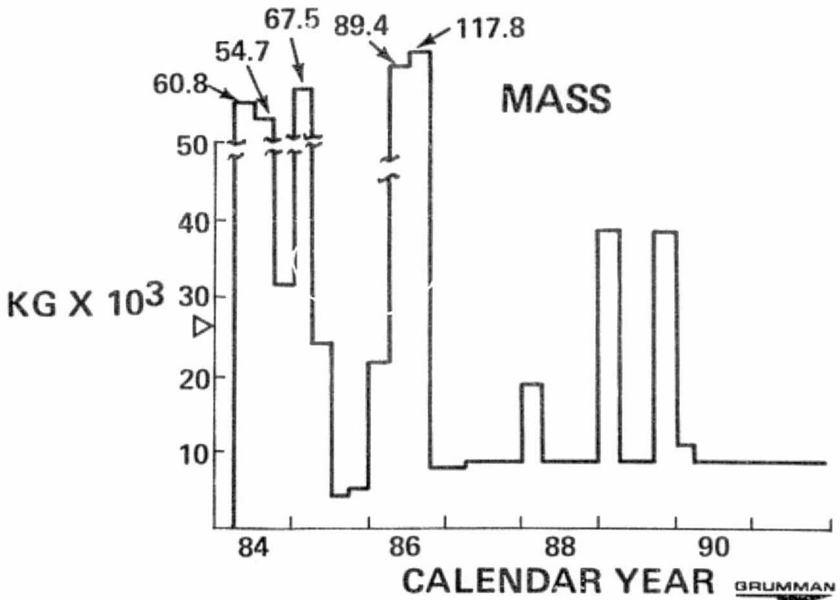
INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR

OPTION 2B-LEO









GRUMMAN

▷ SHUTTLE CAPABILITY

F-360

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INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR OPTION 2B – GSO

These graphs summarize the integrated SCB requirements for the time period 1984 through 1991. These requirements are for use in determining transportation requirements, design modifications and program costs.

This program option is characterized by a GSO DEMO BASE which grows into a SPACE OPS BASE. In 1991, the SPACE OPS BASE assembles the NAV & SURV PSP.

Since the GSO DEMO BASE is not permanently manned, it is periodically visited by GSO sortie flights which provide habitation for the crew. The GSO sortie flight also provides the necessary support (crew and electrical power) to (1) integrate and service the three PSP antennas, and (2) service the 2 mw SPDA/RT. A two man servicing crew is required for each GSO sortie flight; the required 5 kw electrical power (for PSP integration and 2 mw SPDA/RT service) is supplied by the servicing OTV and/or equipment being serviced.

Of the 10 kw of electrical power which are required for the GSO DEMO BASE in 1986, five are required for flight control and five kw are required to support man in demonstrating his ability to perform tasks in GSO. Whenever the base is unoccupied, i.e. whenever the GSO sortie flight returns to LEO orbit, 5 kw are required for flight control purposes. The GSO DEMO BASE 18 kw peak is attributed to STO operation and flight control. The 28 kw peak which occurs in 1990 during SPACE OPS BASE operation is attributed to flight control, habitation/subsystems, STO and NAV & SURV PSP assembly activities. The STO and habitation/subsystems operation activities are the two electrical drivers with 13 kw and 10 kw, respectively.

The major drivers contributing to the peaks appearing on the mass curve are as follows:

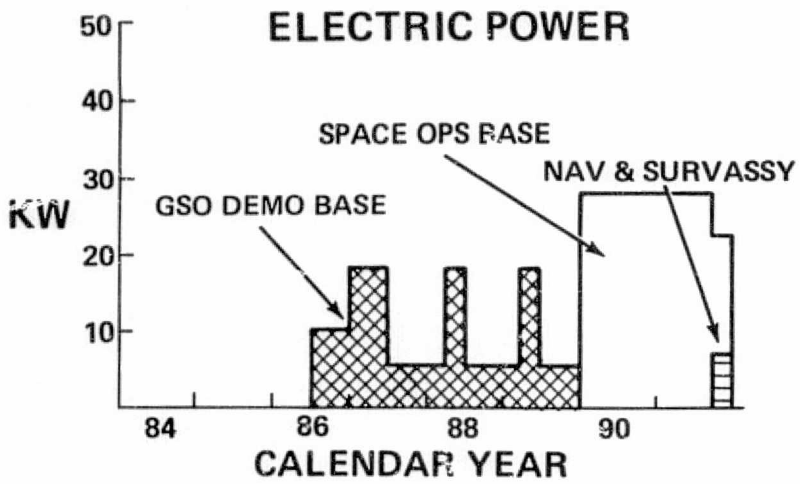
- 1985 – PSP-1 orbit transfer from LEO to GSO.
- 1986 – GSO DEMO BASE orbit transfer from LEO to GSO
- 1988 – PSP-2 and 2 mw SPDA/RT orbit transfer from LEO to GSO
- 1989 – PSP-3 orbit transfer from LEO to GSO
- 1990 – SPACE OPS BASE orbit transfer from LEO to GSO
- 1991 – NAV & SURV assembly.

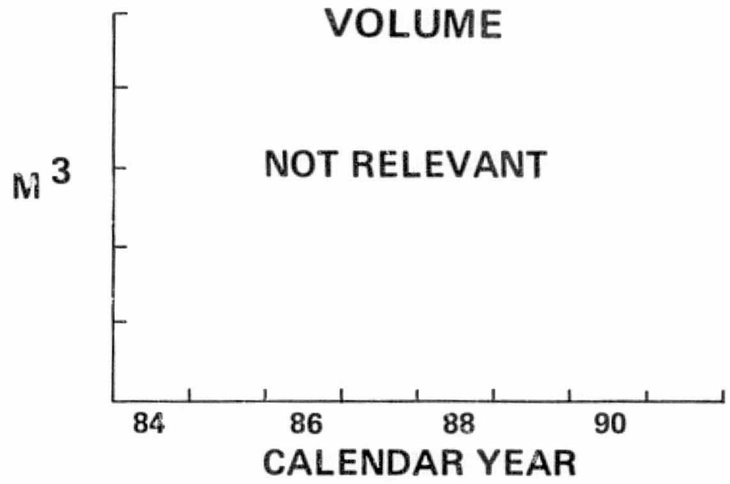
Approximately 1.5 kilograms of mass are required per quarter from 1990 through 1991 for crew rotation, expendables, RCS propellant and spares.

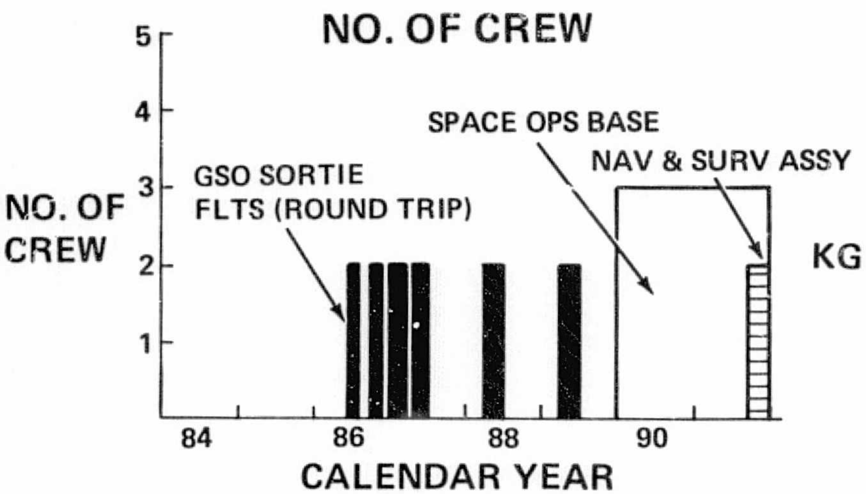
F369T

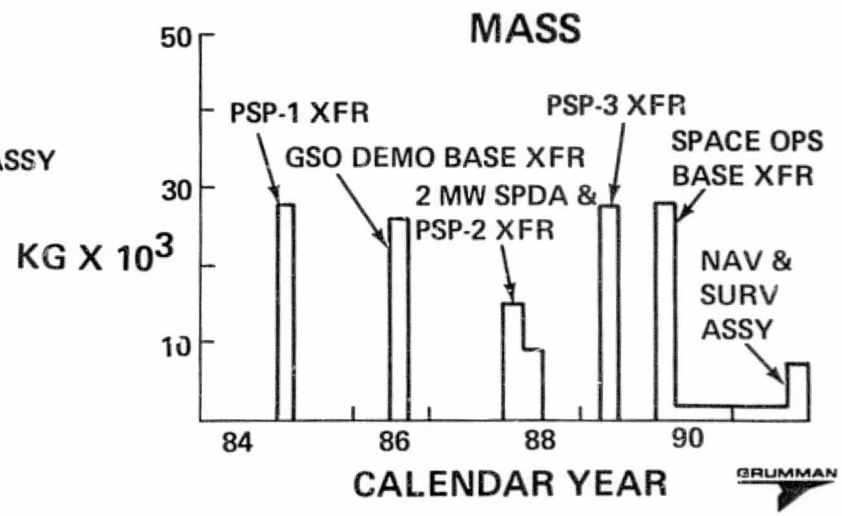
INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR

OPTION 2B-GSO









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GRUMMAN

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INTEGRATED SCB REQUIREMENTS IN ORBIT
BY QUARTER YEAR
OPTION 3-LEO

These graphs summarize the integrated SCB requirements for the time period 1984 through 1991. These requirements are for use in determining transportation requirements, design modifications and program costs.

Manpower requirements (NO. OF CREW) peak at 10 men in 1990. The average manpower requirement for the initial SCB is five men; for the advance SCB, it is eight men. The crew for the FLT OPS & OTHER category builds up to five men in 1986 and remains constant through 1991. Of the five men, three are required to man the SPS and LIFE SCI labs. The PSP and 2mw SPDA/RT construction tasks require two men for each activity. The ramps which appear on the SPACE MFG curve are a function of when the biological, solidification and crystal branch modules come on line. Two men are borrowed from the FLT OPS & OTHER category to assemble the Orbital Depot in 1989.

Electrical power requirements peak at approximately 70 kw in 1990. The peak electrical power requirements for the initial SCB is approximately 27 kw of which 18 kw are attributed to the FLT OPS & OTHER category and 7 kw to PSP-1 construction. Of the 18 kw attributed to FLT OPS & OTHERS 10 kw are required for the SPS lab. With regard to the advance SCB, the electrical power builds to a 70 kw peak in the first quarter of 1990, drops to approximately 61 kw for the remainder of the year and peaks again to 70 kw in the first quarter of 1991. Thereafter it drops to 61 kw and remains constant. The PSP construction during 1984, 1990 and 1991 require approximately 7 kw. The 2 mwSPDA/RT construction in 1986 requires approximately 11 kw. The SCB BUILD-UP & C & O activities, i.e. the initial and advance SCB assembly, and the Orbital Depot assembly, require approximately 5 kw.

The major drivers contributing to the peaks appearing on the MASS and VOLUME curves, and to a degree on the NO. OF CREW and the ELECTRIC POWER are as follows:

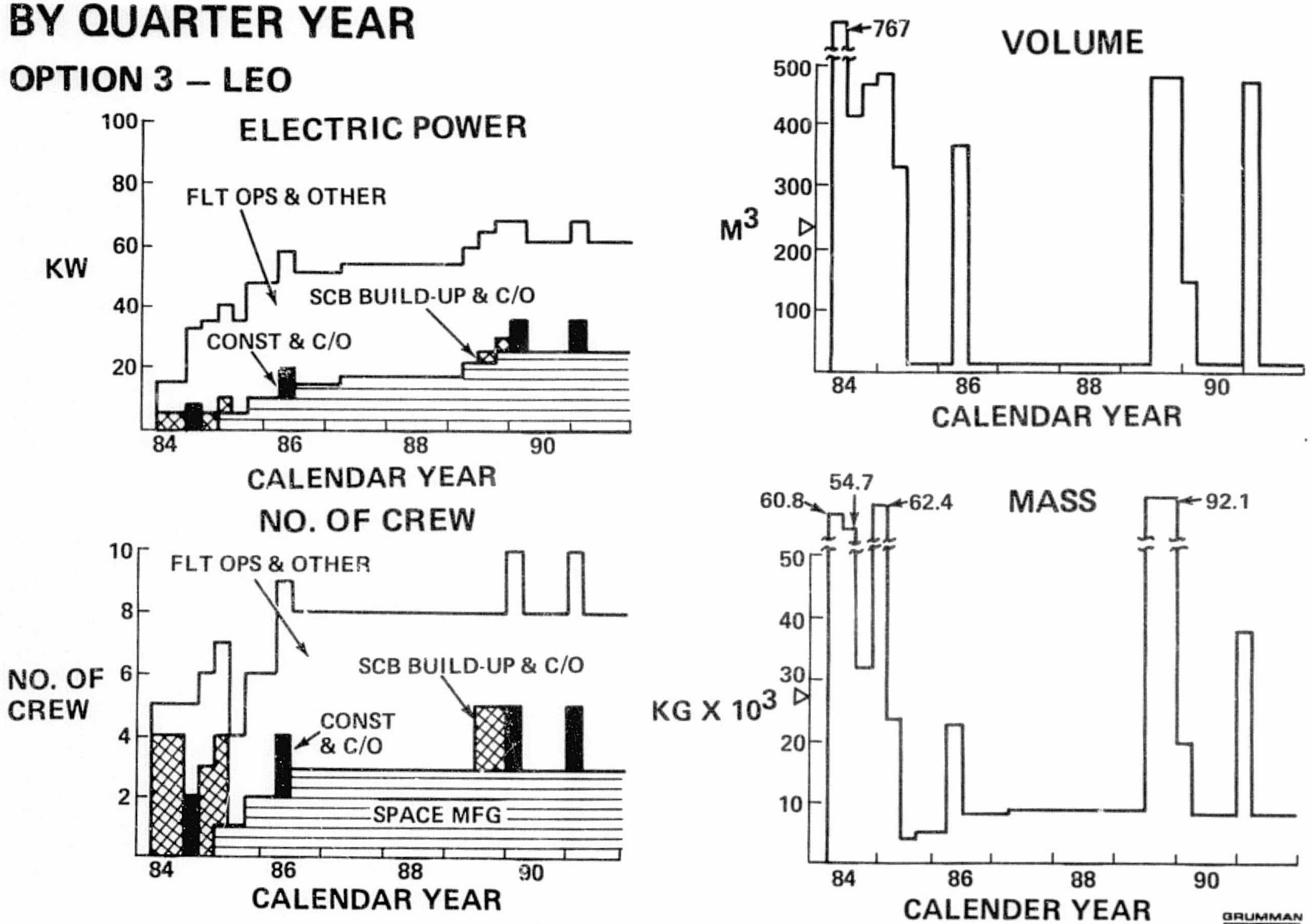
- 1984 — LEO initial SCB build-up, PSP-1 construction
- 1985 — LEO advance SCB build-up
- 1986 — 2mw SPDA/RT construction
- 1989 — Orbital Depot build-up
- 1990 — PSP-2 construction
- 1991 — PSP-3 construction.

Approximately 8000 kilograms of mass and 8 m^3 of volume are required per quarter from 1984 through 1991 for crew rotation, expendables, RCS propellant, space manufacturing materials and spares.

F-370T

INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR

OPTION 3 – LEO



▷ SHUTTLE CAPABILITY

GRUMMAN

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F-370

INTEGRATED SCB REQUIREMENTS IN ORBIT
BY QUARTER YEAR
OPTION 3-GSO

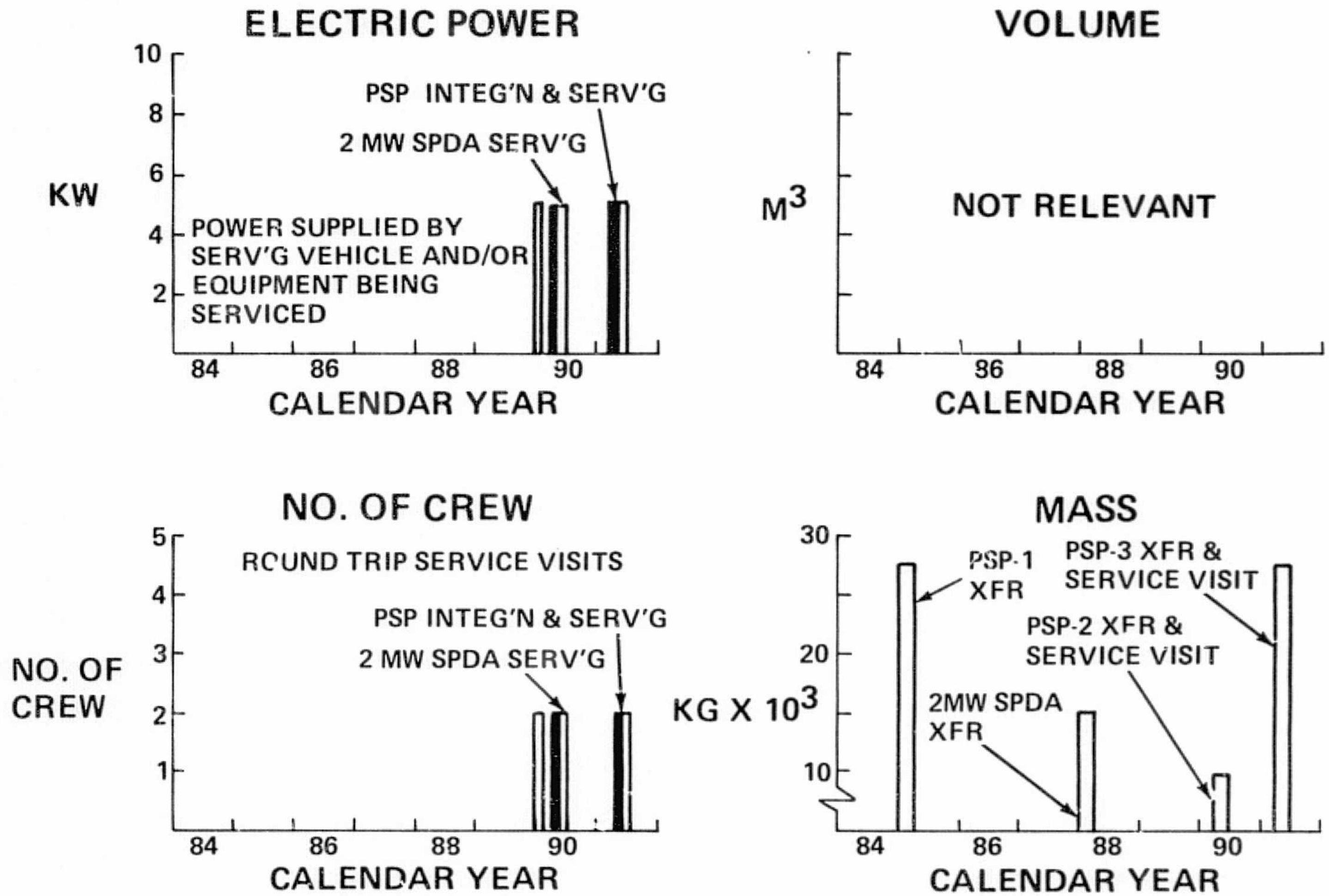
These graphs summarize the integrated SCB requirements for the time period 1984 through 1991. The data are used to determine transportation requirements, design modifications and program costs.

This program option is characterized by GSO sortie flights which provide the necessary support (crew and electrical power) to (1) integrate and service the three PSP antennas and (2) service the 2mw SPDA/RT. A two man servicing crew is required for each GSO sortie flight; the required 5 kw electrical power is supplied by the servicing OTV and/or the equipment being serviced. The PSP-1 and the 2mw SPDA/RT are transferred from LEO to geostationary orbit by an IUS/SEPS combination vehicle; PSP-2 and -3 are transferred via the OTV.

F-358T

INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR

OPTION 3 – GSO



GRUMMAN

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INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR OPTION 3 – LEO/HI INCL

These graphs summarize the integrated SCB requirements for the time period 1984 through 1991. The data are used to determine transportation requirements, design modifications and program costs.

This program option is characterized by a Solar Terrestrial Observatory/Earth Resources facility (STO/ER) in high inclination low earth orbit (LEO HI/INCL).

A three-man crew mans the STO/ER. All three men are required to assemble the STO/ER. After the STO/ER is assembled, two of the three men assemble the earth resources antenna. The remaining crewman monitors flight operations. After the earth resources antenna assembly is completed, the two crewmen activate the STO and earth resources labs.

Electrical power peaks at 25 kw in 1986 and remains constant thru 1991. The 25 kw peak is attributed to flight control/habitation/subsystem operation (10 kw) and STO/ER lab operation (15 kw). The STO requires 13 kw.

The major drivers contributing to the peaks appearing on the MASS and VOLUME curves are as follows:

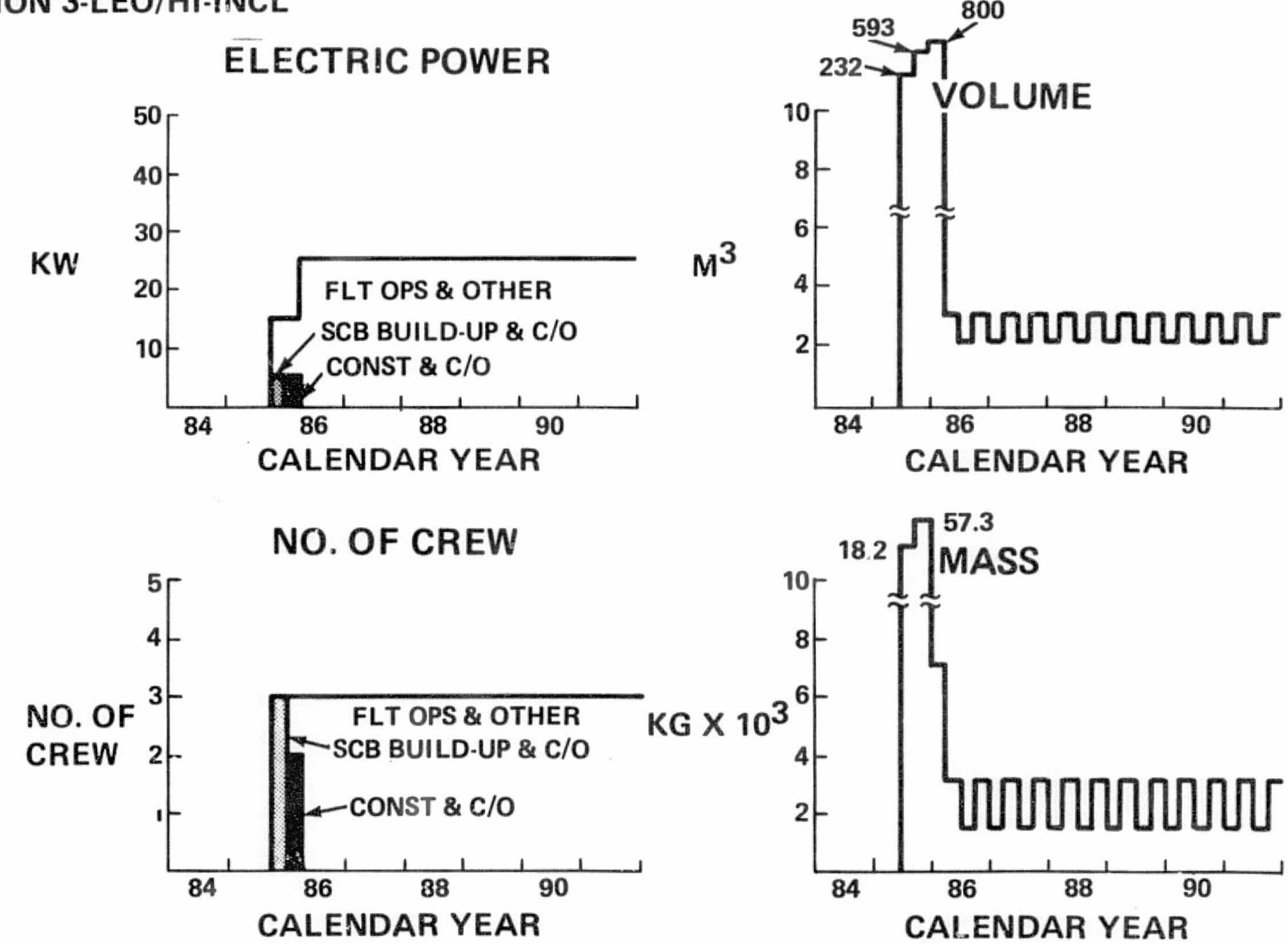
- 1985 – STO/ER assembly
- 1986 – Earth Resources assembly.

The curve from the second quarter of 1986 through 1991 represents the resupply mass and volume to support crew rotation, expendables, RCS propellant and spares. The lower value of the resupply curve (1402 kg) represents RCS propellant which is carried to orbit every other quarter. The peak value (3053 kg) represents crew rotation, expendables and spares.

F368T

INTEGRATED SCB REQUIREMENTS IN ORBIT BY QUARTER YEAR

OPTION 3-LEO/HI-INCL



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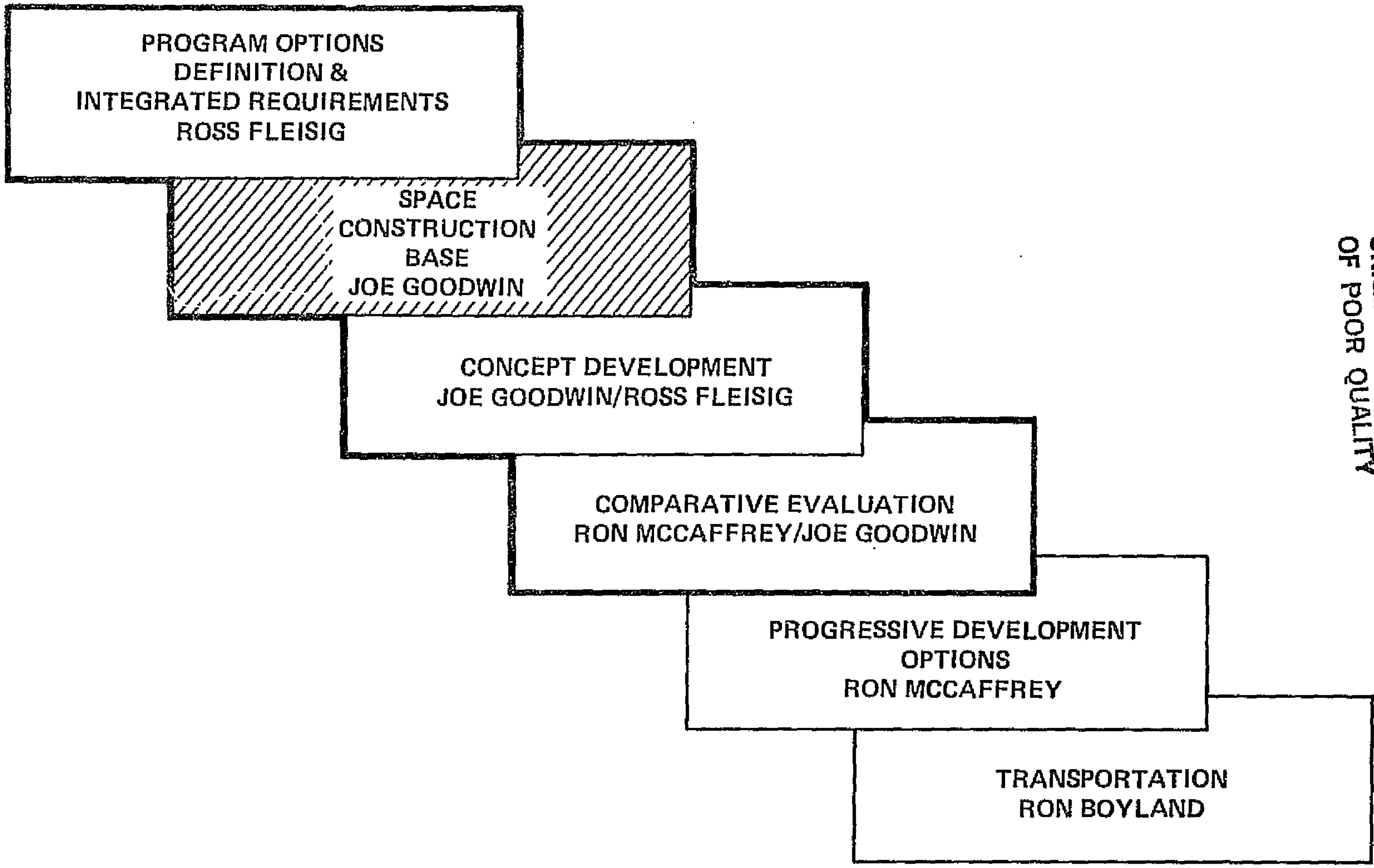
VOLUME 2 – PROGRAM OPTIONS



K-316(A)

SPACE CONSTRUCTION BASE TOPICS

- CONFIG EVOLUTION & RE-USE OF STS EXT TANK
- CONFIGS LEO/28½ DEG & ORBITAL DEPOT
- OTHER CONFIGS
- MODULE COMMONALITY
- SUBSYSTEMS GENERAL REVIEW
- SELECTED SUBSYSTEM DATA

GRUMMAN

PROGRAM OPTION – MAJOR CHARACTERISTICS

Option 1A/B has the SCB starting in 1984 with introduction of the Orbital Depot in 1990 to handle OTV flights. A contruction base in LEO, dedicated to building SPS, is started in 1990. A space operations base starts in 1993. The difference between 1A and 1B is that a 150 kw SPDA to power the SCB in 1984 is built by sortie flights in 1983 for Option 1A but in Option 1B, that SPDA is built by the SCB as its first task. This difference is too small to appear on the chart.

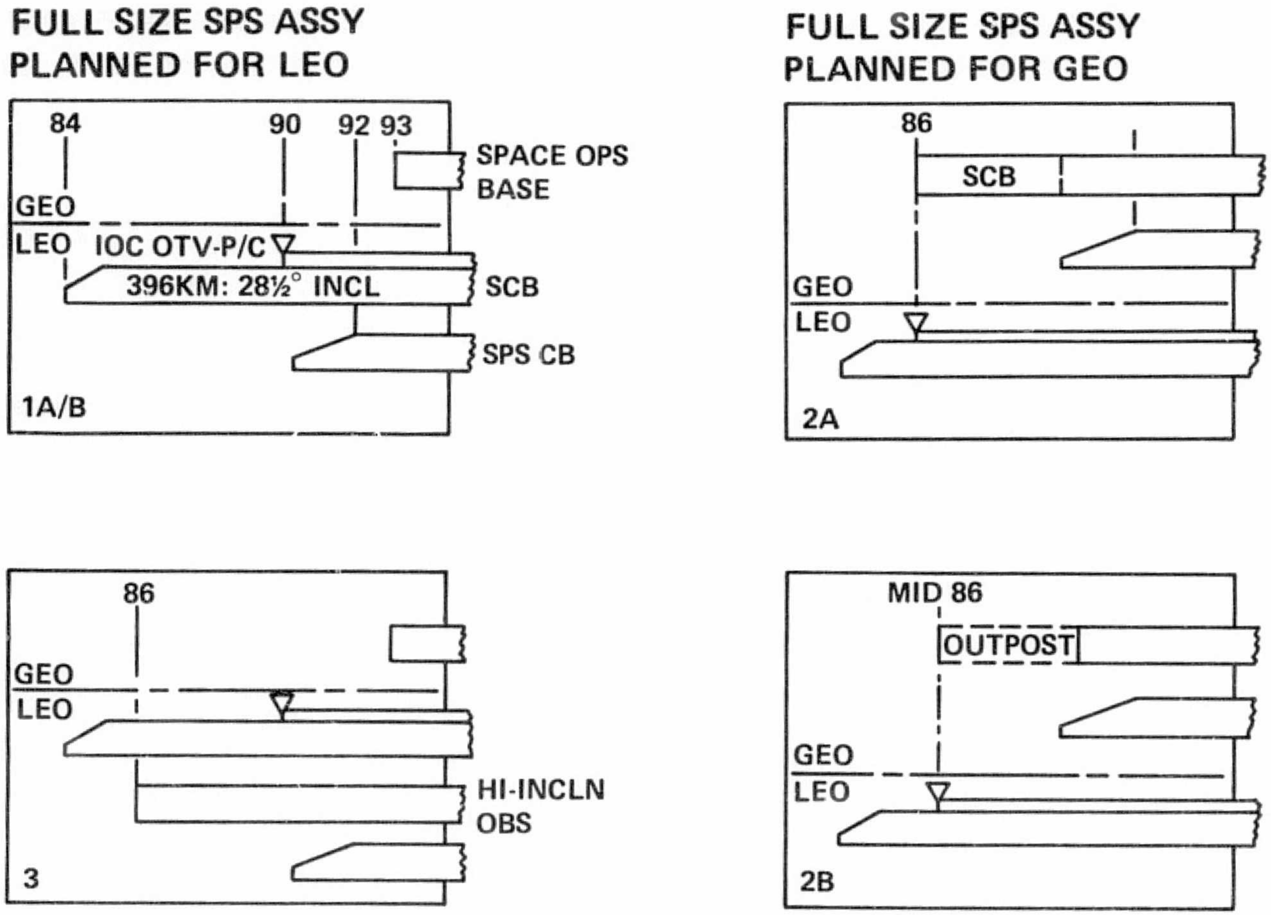
Option 3 is identical to Option 1A except that an observatory flying in LEO, high inclination, is added to entirely accommodate STO requirements.

Option 2A differs from Option 1A in the following respects. The SPS is built in geostationary although its construction base IOC is the same. An SCB to build a 2 mw SPDA in geostationary is commissioned in 1986 which requires that the Orbital Depot to handle OTV's is brought forward to the same year.

Option 2B is the same as Option 2A except that the 2 mw SPDA is built in LEO, as in Option 1A. This leads to a minimally operational outpost being provided in 1986 in geostationary to monitor the environment on man as an input to the SPS "go/no go" decision in 1987. This, in turn, requires the Orbital Depot in 1986.

G339T

PROGRAM OPTION – MAJOR CHARACTERISTICS



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G-339

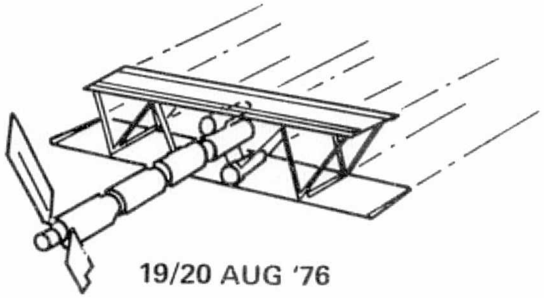
LEO ADVANCED CONST BASE CONFIG EVOLUTION

The Advanced Construction Base defined at the end of Part 1 of the study had construction facilities for the 2 mw SPDA similar to those in the current base. They were, however, structurally interconnected by trussed beams. Habitation, subsystems and laboratories were accommodated in common sized modules. A solar array was attached to the outboard module.

At the beginning of October 1976 the modules assembly longer. This provided a long spine which gave tubes between them to make the modules assembly longer. This provided a long spine which gave a suitable base for the construction of the PSP antenna. That construction was performed on the Initial Construction Base before it evolved into the Advanced Base with its more sophisticated construction capability.

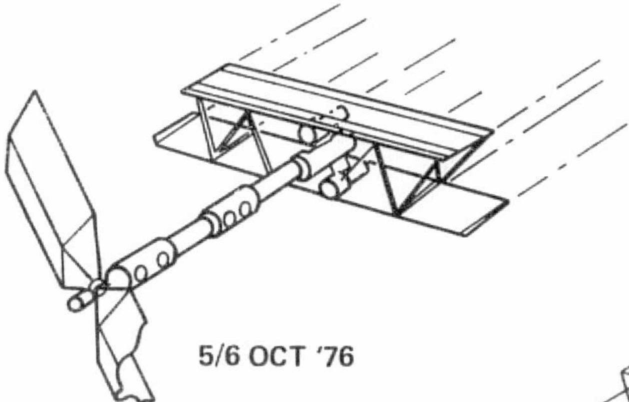
In mid-October, the use of STS external tanks as a long structural spine was introduced. This provided a general purpose platform upon which to mount the construction facilities for the 2 mw SPDA and earlier, a long base for building the PSP antenna. The modules could now revert to a more compact grouping.

LEO ADVANCED CONST BASE CONFIG EVOLUTION
SHEET 1 OF 2



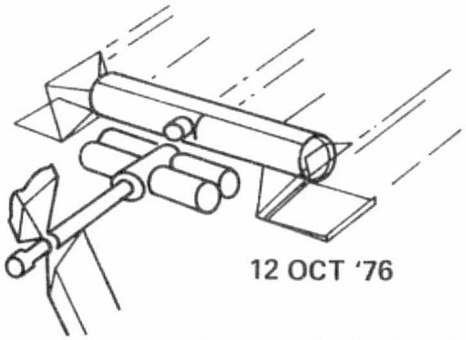
19/20 AUG '76

- AT END OF PART 1



5/6 OCT '76

- HABITATION SPINE EXTENDED TO AID PSP ASSY



12 OCT '76

- FIRST USE OF STS EXT TANKS AS GEN PURPOSE ASSY PLATFORM
- MORE COMPACT GROUPING OF MODULES

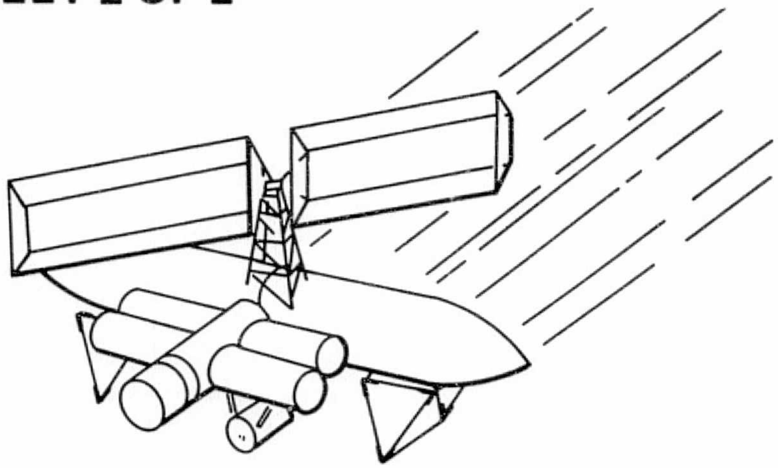
LEO ADVANCED CONST BASE CONFIG EVOLUTION

It was realized in November 1976 that the 150 kw SPDA solar array, as then located, could interfere with the 2 mw SPDA construction unless restrictions were placed on time of construction to suit the attitude of the array. This was not practical so the SPDA was relocated as shown on the figure. figure.

Inertia calculations for the November 1976 configuration gave high inertias about all three orthogonal axes. This high inertia was only acceptable for pitch about the axes normal to the longitudinal axis of the base, which is aligned with the local vertical. To improve the other inertia characteristics, and thus minimize control propellant requirements, the 150 kw SPDA and the habitation, subsystems and laboratory modules were relocated to their present positions.

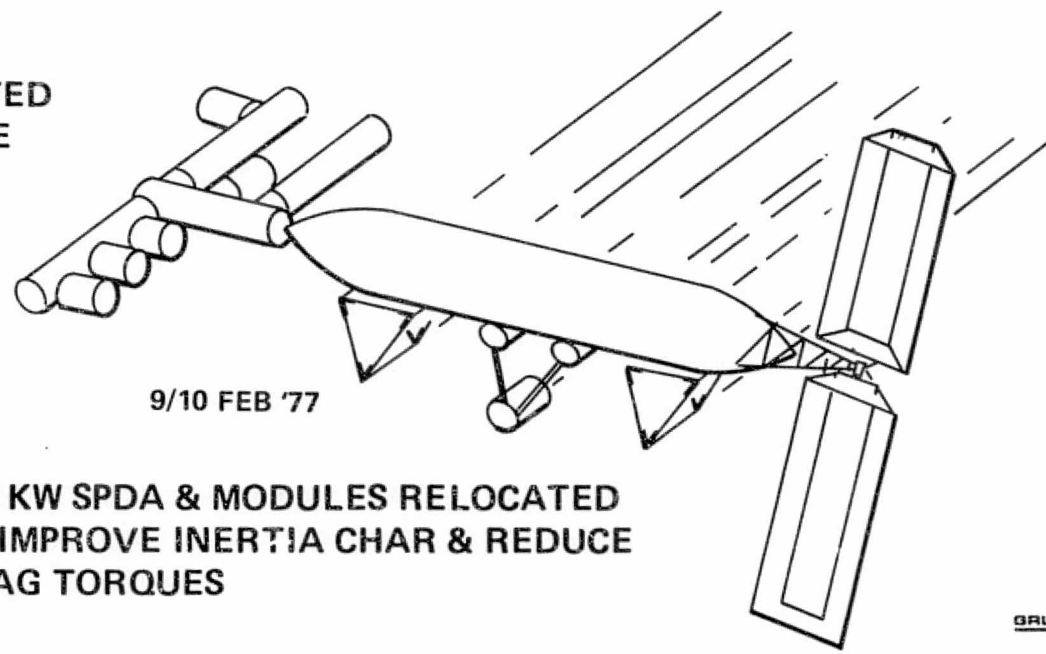
G311T

LEO ADVANCED CONST BASE CONFIG EVOLUTION
SHEET 2 OF 2



30 NOV '76

- 150 KW SPDA RELOCATED TO CLEAR CONST ZONE



9/10 FEB '77

- 150 KW SPDA & MODULES RELOCATED TO IMPROVE INERTIA CHAR & REDUCE DRAG TORQUES

GRUMMAN

PAYLOAD PENALTY FOR CARRYING EXTERNAL TANK TO ORBIT

The Shuttle Transportation System (STS) External Tank can be carried to 28½ deg inclination orbit with little penalty to the STS payload capability. During normal STS launches the external tank is carried to main engine cutoff (MECO). The additional delta velocity required to carry the tank to orbit is estimated to be:

DELTA VELOCITY REQUIREMENT	400 km	500 km
MECO to apogee burn, m/sec	89	121
Circulation at apogee, m/sec	93	116
Rendezvous & Docking, m/sec	44	44

It is assumed that all delta V burns subsequent to MECO are performed with the Orbital Maneuvering System (OMS). Pertinent values used in calculating the penalty for orbiting the external tank include:

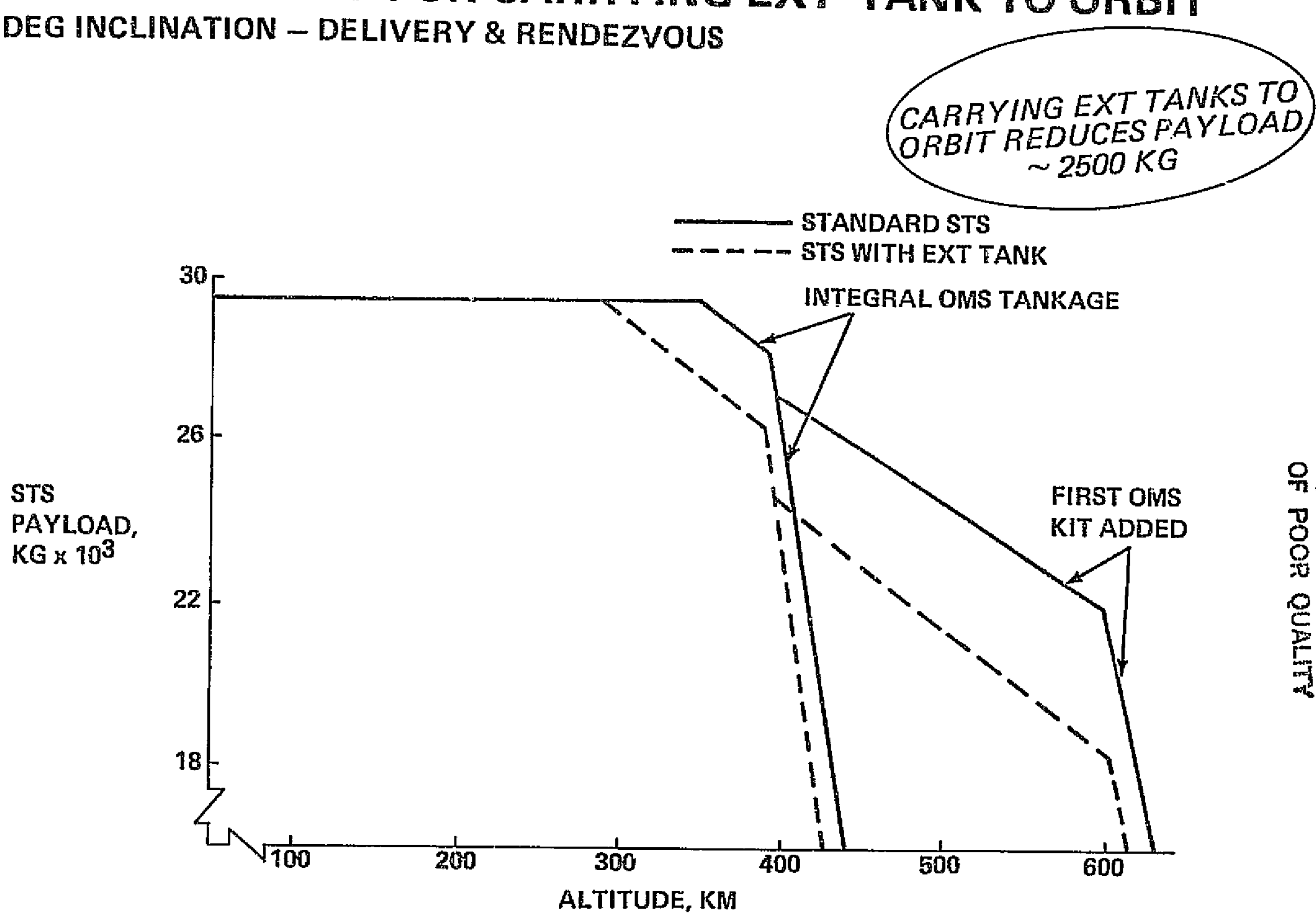
STS weight loss during coast to apogee	=	2,734 kg
STS weight at MECO	=	148,493 kg
Ext. Tank weight at MECO	=	34,561 kg
OMS engines nominal I_{sp}	=	312 sec

Based upon the foregoing assumptions the STS payload penalty for carrying the External Tank to a 400 km-28½ deg orbit (including rendezvous) is calculated to be 2463 kg. 500 km penalty is 3037 kg.

G331T

PAYLOAD PENALTY FOR CARRYING EXT TANK TO ORBIT

28½ DEG INCLINATION – DELIVERY & RENDEZVOUS



USE OF THE STS EXT TANK IN ORBIT OPTIONS

. Use of the STS external tank as part of the SCB is an attractive option. The chart shows possible tank modifications whose complexity increases with use.

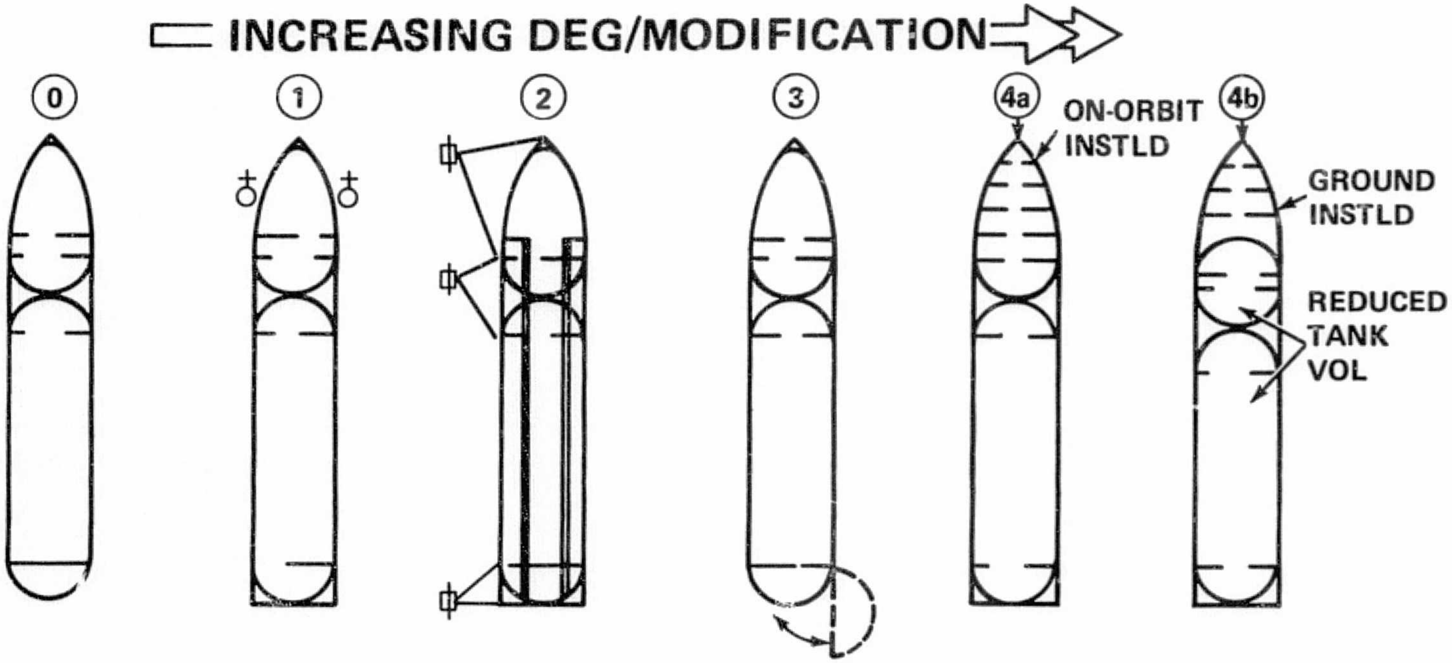
An unmodified tank can be used in orbit as a source of raw material for manufacture or as mass driver reaction. A tank with some attachment points added is useful as a mass to govern inertia characteristics of an SCB or as a stiff spine. The current LEO SCB uses two tanks joined together at their aft ends to provide a long structural spine and includes external rails to carry a transportation carriage. The above modifications are external to the tank and are effected on the ground.

Internal modifications to the tank range from an end dome opening as a swing door to provide shelter, to internal habitation and installation of subsystems hardware inside the tank, either in orbit or on the ground.

G342T

USE OF THE STS EXT TANK IN ORBIT

OPTIONS



MODIFICATION:

0	1	2	3	4a, 4b
/	JOINT ADAPTER RCS/FLT CONT	EXTNL RAILS JIG ATTACHMT POINTS	SWING DOOR	HABITATION SUBSYSTEMS

USE:

0	1	2	3	4a, 4b
SOURCE OF RAW MATERIAL FOR: • RECYCLED ALUM • MASS DRIVER REACTION	HIGH INERTIA SPACE SPINE	CONST BASE SPINE	SHELTER	LIVING QUARTERS

GRUMMAN

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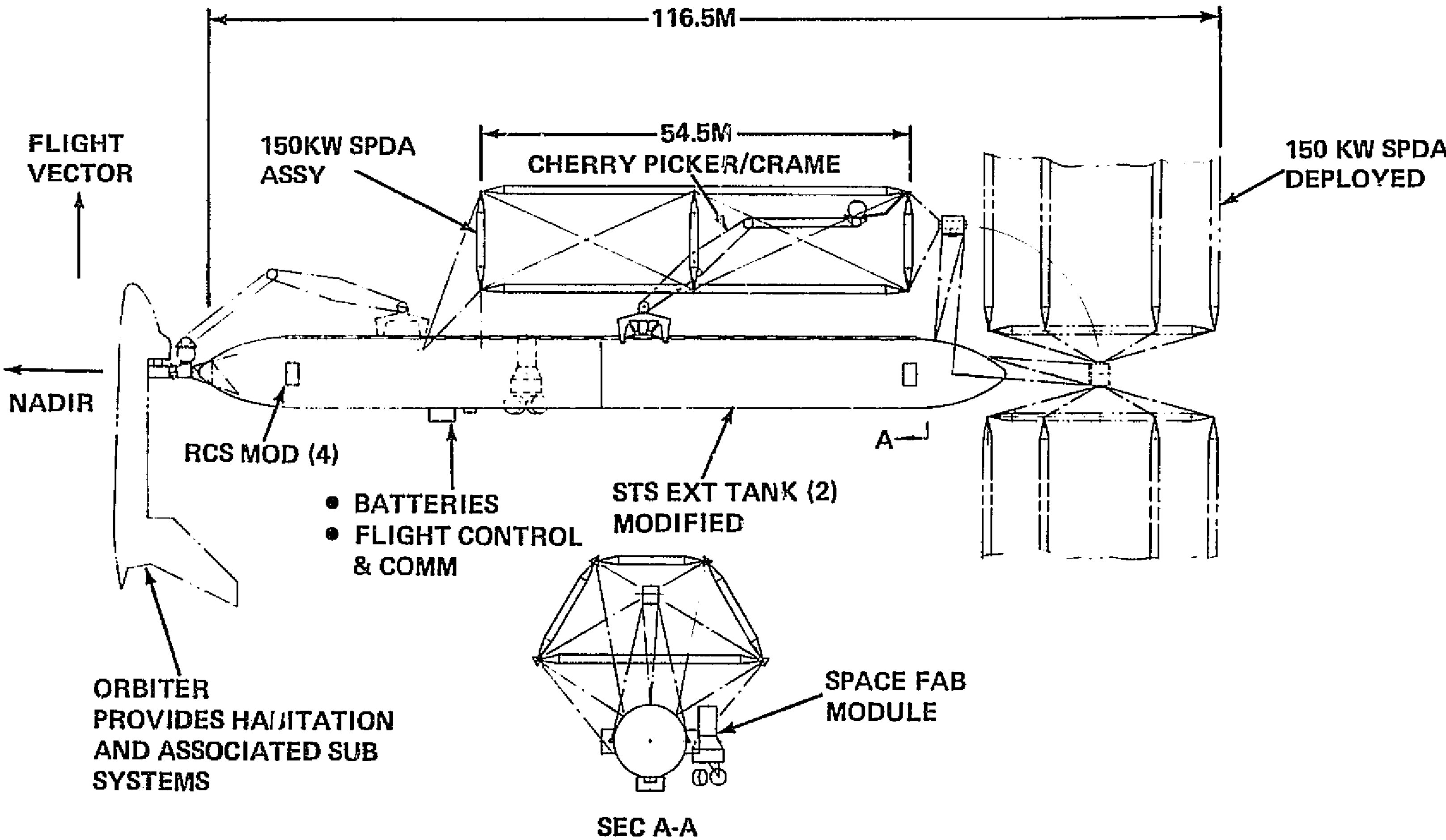
TENDED SPACE CONSTRUCTION BASE – LOW EARTH ORBIT, 28½° INCLINATION

The tended-SCB configuration has many features common to the initial construction base, such as the modified external tanks, Cherry Picker/Crane, space fabrication module and 150 kw SPDA power source. The 150 kw SPDA is the first item constructed and is shown being assembled as well as finally deployed at one end of the external tank "strong back". A docking tunnel is provided at the other end of the "strong back" to facilitate crew transfer to the Cherry Picker/ Crane. In addition, RCS and flight controls are provided for normal station keeping functions.

MC-·-·.9T

TENDED SPACE CONSTRUCTION BASE
LOW EARTH ORBIT, 28½ DEG INCLINATION



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GRUMMAN

STS LAUNCH CAPABILITY FROM KSC TO 396 KM – 28½ DEG ORBIT

The chart on the opposite page shows the STS launch capability with integral OMS tanks to a 396 km, 28½ degree orbit from Kennedy Space Center.

Various combinations of STS flight requirements result in different payload capabilities. The flight requirements investigated include: rendezvous, docking, and delivery of the external tank. Each of these requirements affects the payload weight the STS is capable of delivering. The docking requirement affects the payload capability in terms of length and volume.

The payload weight capabilities are derived using the following information:

	PAYLOAD WEIGHT' KG	
	Delivery Only	Delivery and Rendezvous
Standard STS payload capability (from Space Shuttle System Payload Accomodations – Volume XIV Rev D)	29,500 29,500	28,000 28,000
Payload Chargeable Docking Option (Same Reference)	1,769	1,769
Penalty to Deliver – External Tanks (calculated from information provided elsewhere in this report)	1,996	2,463

G412T

STS LAUNCH CAPABILITY FROM KSC TO 396 KM 28½° ORBIT

PAYLOAD CAPABILITIES VARY

	PAYLOAD CAPABILITY				
RENDEZVOUS	NO	NO	YES	YES	YES
DOCKING	NO	NO	NO	YES	YES
WITH EXT TANK	NO	YES	YES	YES	NO
WEIGHT, KG	29,500	27,504	25,537	23,768	26,231
LENGTH, M	18.3	18.3	18.3	16.0	16.0
VOLUME, M^3	300	300	300	262	262

GRUMMAN

G-412

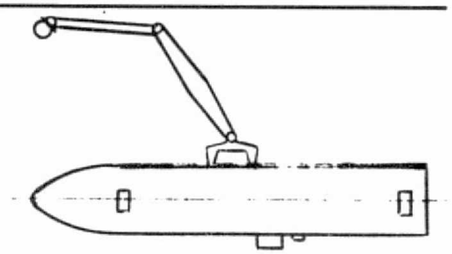
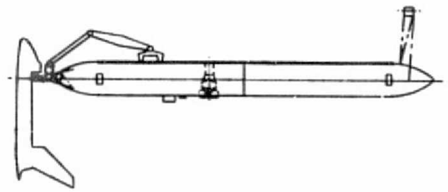
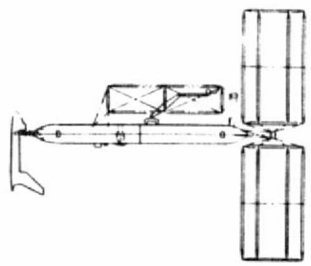
BUILD UP OF TRANSITION PHASE SCB WITH STS EXT TANKS

Two shuttle flights are necessary to launch all components of this configuration. During the first flight, of four days duration, the modified external tank is deposited in orbit. The tank modifications include the Cherry Picker/Crane rails, hard points with fittings for subsystem additions and the aft skirt. The aft skirt has docking and indexing provisions enabling coupling to another external tank. Prior to releasing the tank, the batteries, RCS modules (4), flight control/communication and Cherry Picker/Crane are removed from the STS payload bay and attached to their respective positions. It should be noted that the batteries shown are those used with the 150 kw SPDA and are utilized prior to SPDA construction for station keeping power.

The second flight, of 14 days duration, starts operations with rendezvous and soft dock of the external tanks. Hard docking is achieved by astronaut EVA by installing bolts or operating latches. The docking interface is then attached to the nose of the first external tank. Two RCS modules are removed from the first tank and attached to the second. The STS now separates and docks to the docking interface. The Automatic Fabrication Machine (AFM) and the SPDA rotary joint/tower are removed from the payload bay by the Cherry Picker/Crane and attached to their respective locations. Fabrication and assembly of the 150 kw SPDA is performed and the SPDA is rotated 90 deg and fixed in its flight attitude.

G384T

BUILD UP OF TRANSITION PHASE SCB
WITH STS EXT TANKS

FLT NO.	CONST CREW STS	CONST CREW SCB	STS PAYLOAD MAJOR ITEMS	STS PAYLOAD WT KG X 10^2	STS PAYLOAD VOL M^3	DAYS		CONFIG
1	3		• EXT TANK NO. 1 • RCS • BATTERIES • CHERRY PICKER/CRANE • STAB & CONTROL	22.8	184	4	SCB CONST	
			DAYS TO NEXT FLT			26		
2	3		• EXT TANK NO. 2 • AUTO FAB MODULE • DOCKING • PSP TURNTABLE • SPDA ROTARY JOINT & MAST • SOLAR BLANKETS & MIRRORS	19.5	152	6	SCB CONST	
						18	SPDA CONST	

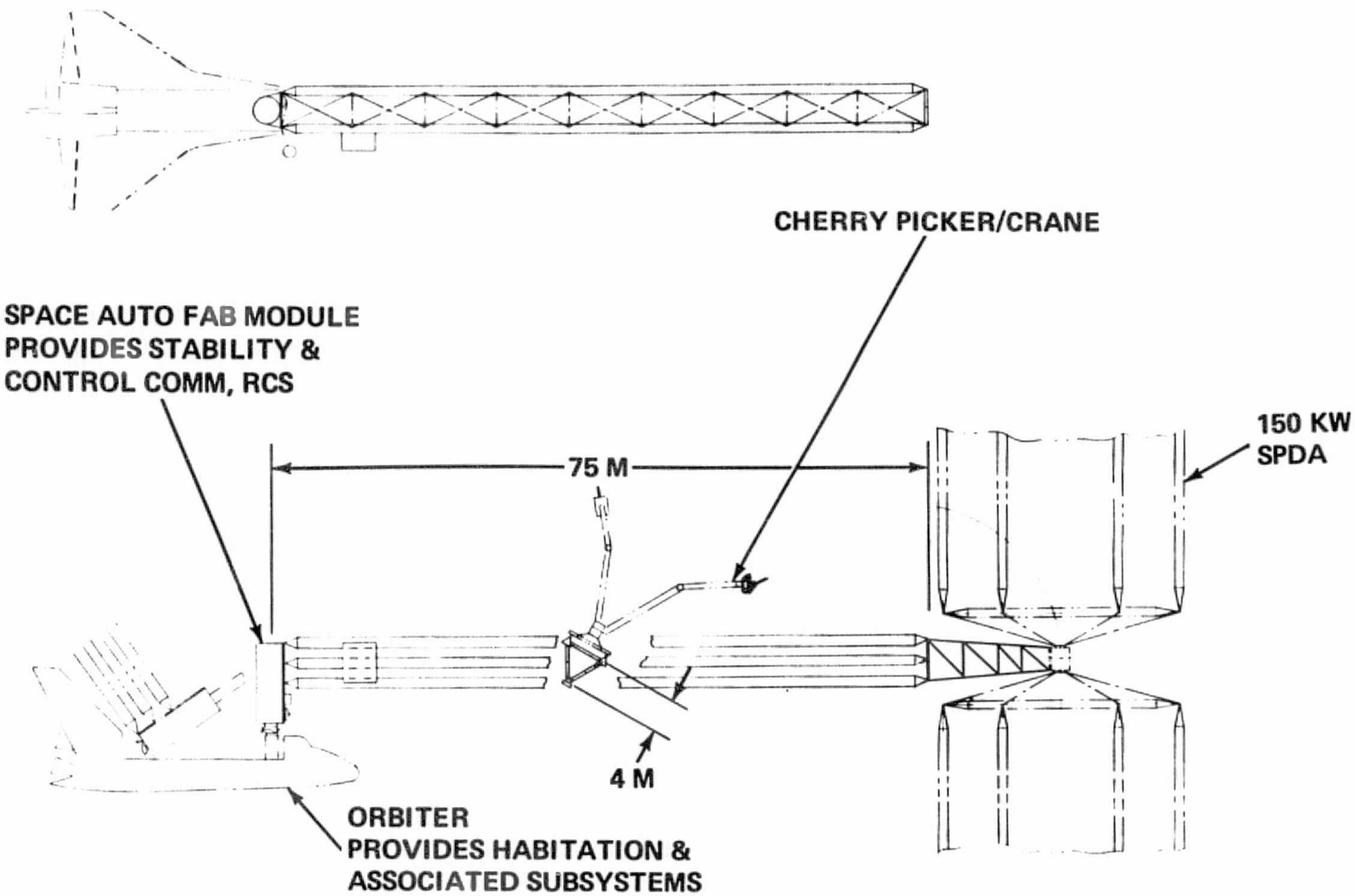
GRUMMAN

G-384

TENDED SCB – NO EXT TANKS – LEO, 28½ DEG INCL.

This configuration consists of a free flying automatic fabrication machine (AFM), a triangular structure whose long members were fabrication by the AFM, a Cherry Picker/Crane and 150 kw SPDA. A docking interface providing shirtsleeve transfer to the Cherry Picker can be attached to the AFM or attached to the orbiter docking ring. The overall length was selected so that the Cherry Picker/ Crane rail was approximately the same length as in the external tank versions. The 4m cross sectional size was limited by a platform integral to the AFM constrained to fit within the confines of the orbiter payload bay, additional RCS is added along the length of the structure to complete the configuration.

TENDED SCB – NO EXTERNAL TANKS
LOW EARTH ORBIT, 28-1/2 DEG INCLINATION



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GRUMMAN

MC-328

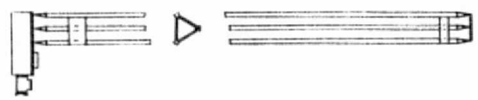
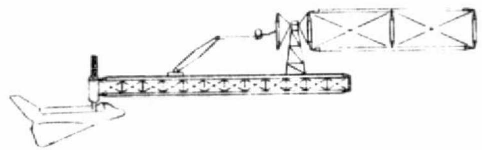
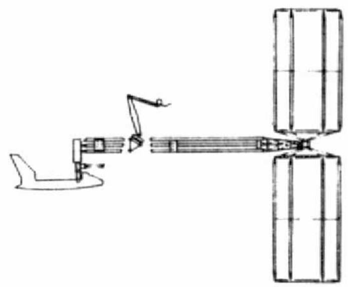
BUILD UP OF TRANSITION PHASE SCB-NO STS EXT. TANKS

Two shuttle flights are required to launch all of the components of this configuration. The first flight, of 13 days duration, brings up the Automatic Fabrication Module (AFM), Cherry Picker/Crane (C-P/C) rails, SPDA batteries and RCS packages. The AFM has free flying capability, and in addition, has a platform attached to it to provide a base for the fabricated structural members. The build up starts with the AFM rotated to its fabricating position. The structural members are built, captured by the STS manipulator (RMS) and attached in their final position on the platform. The structure is completed by the addition of cross members and tension cable bracing, installed by astronauts during EVA. The rails are then brought out in sections and attached to the structure. The RCS package and SPDA batteries are then attached. The resultant assembly is a free flying arrangement and is released into orbit.

The second flight, of 22 days duration, carries the necessary items to complete the configuration. These include the Cherry Picker/Crane (C-P/C) and all of the components of the 150 kw SPDA. Initially the C-P/C is removed from the STS payload bay by the RMS and placed on the rails. After checkout, the C-P/C is used to install the SPDA tower/rotary joint in its position. The AFM then begins to build the SPDA structure. The C-P/C assembles one half of the SPDA (including solar blanket and mirrors) then rotates it 180 deg to do the other half. Finally, the SPDA is relocated on the end of the SCB structure in its flying attitude.

G383T

BUILD UP OF TRANSITION PHASE SCB
NO STS EXT TANKS

FLT NO.	CONST CREW STS	CONST CREW SCB	STS PAYLOAD MAJOR ITEMS	STS PAYLOAD WT KG X 10^3	STS PAYLOAD VOL M^3	DAYS	CONFIG	
1	3		• AUTO FAB MODULE • RCS MODULE • BATTERIES	26	103	13	SCB CONST	
			DAYS TO NEXT FLT			17		
			• CHERRY PICKER/CRANE • SPDA ROTARY JOINT & MAST • SOLAR BLANKETS & MIRRORS	15	240	4	SCB CONST	
2	3					18	SPDA CONST	

G-383

SUMMARY OF EXTERNAL TANK-ADVANTAGES

This chart summarizes some advantages of using STS external tanks as part of the LEO SCB. The Grumman baseline design employs two of the tanks and makes use of the advantages listed, except for the large internal volume.

G343T

SUMMARY OF EXTERNAL TANK ADVANTAGES

- RAPIDLY AVAILABLE IN ORBIT
- HIGH STRENGTH/HIGH STIFFNESS SPINE
- ROBUST/DAMAGE TOLERANT
- GROUND ATTACHED/PRECISE/STIFF RAILS
- LARGE ATTACHMENT AREA/MANY HARD POINTS
- HIGH INERTIA
- LARGE INTERNAL VOLUME
- LOW PAYLOAD PENALTY

G-343

INITIAL SPACE CONSTRUCTION BASE LEO, 28 1/2° INCLINATION – OPTION 1 A/B, 2A/B & 3

With all program options, the Initial SCB is the first facility in a series of construction bases with developing capabilities.

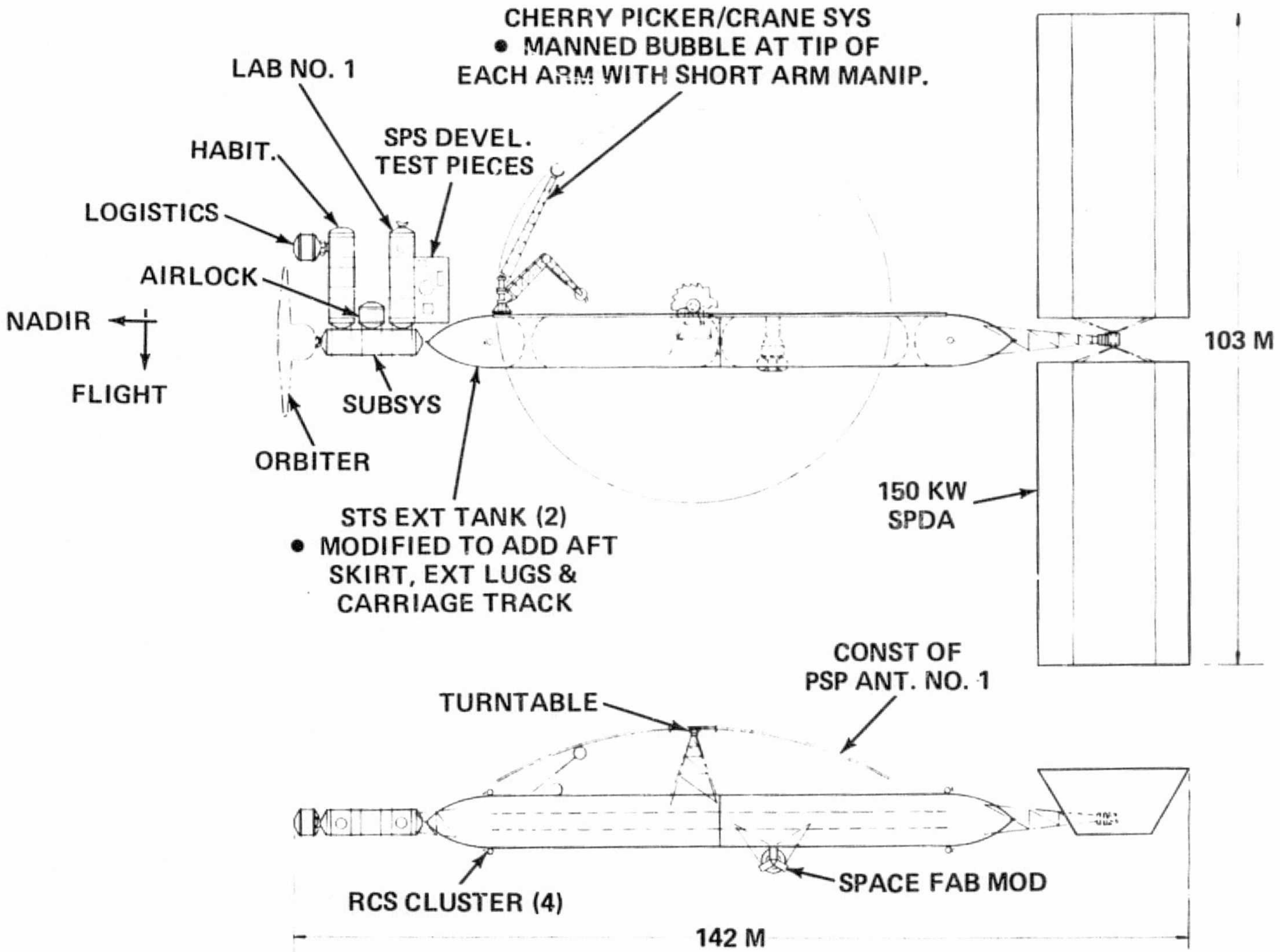
Separate habitation and subsystems modules house the crew and cater for station operations. These two facilities could be combined into one module for this Initial SCB with its crew of five but development of the SCB through to the Orbital Depot calls for more crew and, therefore, more habitation. Hence, separate modules are provided. A logistics module with supplies for 90 days is attached to the habitation module within reach of the shuttle manipulator for exchange of empty and full modules. The external airlock permits EVA. Primary docking for the shuttle is provided on the subsystems module. Emergency docking is on Lab No. 1. This laboratory caters for SPS development and construction testing, inspecting, monitoring, etc. A platform is provided external to the lab for SPS test pieces to check environmental effects, etc. This platform is within reach of the crane manipulators. The 150 kw solar array is an SPDA previously built in orbit from shuttle sortie missions and available for attaching to the SCB to provide power.

Considering the construction facility, this SCB builds the PSP antenna No. 1 whose component parts are brought to orbit in the shuttle and assembled by this facility. A trussed tower mounts a turntable which serves as the assembly base from which the antenna is built radially from its center. The components are handled by the crane manipulator system which has two articulated arms mounted on a carriage which runs along the track attached to the "STS External Tanks" spine. At the tip of each articulated arm is a pressurized bubble housing a man in shirtsleeves operating short arm manipulators. The manipulator docks the bubble to the laboratory for the operator to 'go home'. A space fabrication module is there to provide four 1 m beams which form struts mounting the feed horn to the antenna. With program Option 1B, the construction facility also builds the 150 kw solar array since, in this option, it has not been built previously as an SPDA by shuttle sortie flights.

G304T

INITIAL SPACE CONSTRUCTION BASE

LEO, 28½ DEG INCL - OPTION 1A/B, 2A/B & 3



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GRUMMAN

SCB WEIGHT SUMMARY INITIAL CONSTRUCTION BASE

Weight estimates have been generated to the component level for each subsystem, element, mission hardware and expendable used in all of the Space Construction Bases program options. Space limitations prevent the presentation of all these data in this report. The chart on the opposite page summarizes these weights for the Initial Construction Base.

SCB dry weights include 25% contingency. This contingency is meant to cover forgotten and undisclosed items as well as underestimates. For this reason Grumman, wherever possible, maintains a separate line item for contingency rather than spreading it throughout other line items.

Expendables, construction materials and mission hardware are added to the dry weight to arrive at the total launch weight.

When applicable, the external tank weights and the weight of the orbiting 150 kw SPDA are then added to arrive at the total on orbit weight.

Launch sequences for the initial construction base have been determined based upon STS payload weight and volume restrictions (including the payload penalty for orbiting the external tanks). On the third launch the Habitation Module is orbited and the SCB is manned. Two additional launches result in a fully operational base with Public Service Platform construction capability.

G390T

SCB WEIGHT SUMMARY
INITIAL CONSTRUCTION BASE

- OPERATIONAL AFTER 3RD STS LAUNCH
- FULLY OPERATIONAL AND BUILDING PSP NO. 1 AFTER 5 LAUNCHES

ITEM	WEIGHT, KG
STRUCTURE	24 981
INDUCED ENVIRONMENTAL PROTECTION	1 543
PROPULSION – RCS	340
PRIME POWER – EPS	5 355
AVIONICS	2 242
ENVIRONMENTAL CONTROL	5 505
PERSONNEL PROVISIONS	3 415
OTHER STRUCTURES	
EXT TANK MODIFICATIONS	5 262
AUTO FABRICATION MODULES	3 691
CONSTRUCTION AIDS/DOCKING	5 288
EPS – 150 KW SPDA MODIFICATIONS	2 730
SPARES	930
CONTINGENCY (25%)	15 321
SUBTOTAL – DRY	76,603
CREW, EXPENDABLES	3 288
PROPELLANT	1 208
CONSTRUCTION MATERIALS	20 535
EXPERIMENTS	12 280
SPACE MANUFACTURE EQUIP	—
SPACE MANUFACTURE THROUGHPUT	—
TOTAL – LAUNCH	113,914
EXTERNAL TANKS	68 614
150 KW SPDA	25 090
TOTAL – ON ORBIT	207,618

GRUMMAN

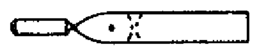
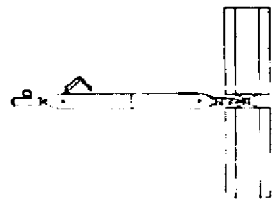
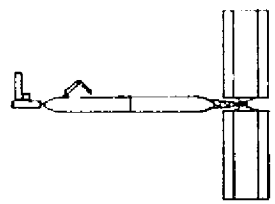
G-390

BUILD UP OF LEO INITIAL SCB

Five shuttle flights are required to launch all components of this configuration. The first flight of three day duration, brings up the Subsystem Module (SSM), docking interface and four RCS modules. After achieving orbit, the RCS modules are installed on the tank. The SSM is then transported to its position on the tank and secured. The docking interface is then brought out and secured to the forward end of the SSM. The other docking interface is temporarily stored for later use. The second flight, lasting six days, rendezvous and soft docks the external tanks. It should be noted that the ground modifications of the tanks included soft docking and indexing provisions, Cherry Picker/Crane (C-P/C) rails and various fittings to accommodate the addition of equipment. Hard docking is achieved by an EVA astronaut adding bolts or operating latches. Two of the four RCS modules are now relocated from the first external tank to the second. The STS now separates from the assembly but flies in close formation. The C-P/C is removed from the payload bay and transported to its position on the tank rails. The airlock is positioned by the C-P/C and bolted to the SSM interface. The 150 kw SPDA tower/rotary joint is then brought ot its operating position and secured. The EVA crewmen fly to the SPDA, energize the power assist package and fly the SPDA to its tower and attach. After checkout procedures the STS deorbits. The third flight, of two days duration, docks to the SSM docking interface. The Habitation Module (HM) is then transported to its position by the RMS and bolted in place. After checkout, the STS de-orbits.

G387T

BUILD UP OF LEO INITIAL SCB
SHEET 1 OF 2

FLT NO.	CONST CREW		STS PAYLOAD			DAYS	CONFIG
	STS	SCB	MAJOR ITEMS	WT KG X 10^3	VOL M^3		
1	3	–	• EXT TANK NO. 1, RCS, • SUBSYSTEM MODULE, • DOCKING RINGS • RCS	24.9	230	3	
			DAYS TO NEXT FLT			27	
2	3	–	• EXT TANK NO. 2, • AIRLOCK • SPDA TOWER • CHERRY PICKER	12.3	272.9	6	
			DAYS TO NEXT FLT			24	
3	0	3	• HABITATION MODULE	23.6	228.7	2	
		3	DAYS TO NEXT FLT			28	

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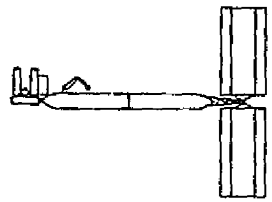
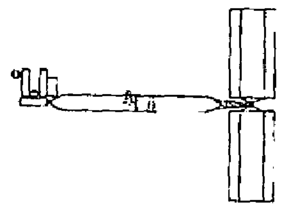
BUILDUP OF LEO INITIAL SCB

The fourth flight, lasting two days, docks to the SSM. The engineering laboratory (EL) is then transported by RMS to its proper position on the SSM and fixed. The docking interface that was stored is brought to the end of the EL and attached. After checkout, the STS deorbits. The fifth and final flight in this sequence is also of two days duration. The final elements, the logistics module, the Automatic Fabrication Module (AFM) and the Public Service Platform (PSP) turntable are delivered and fixed to their respective positions.

G388T

BUILD UP OF LEO INITIAL SCB
SHEET 2 OF 2

FLT NO.	CONST CREW STS	CONST CREW SCB	STS PAYLOAD • MAJOR ITEMS	STS PAYLOAD WT KG X 10^3	STS PAYLOAD VOL M^3	DAYS	CONFIG
4	1	2	• ENGINEERING LABORATORY	25.4	228.7	2	
		5	DAYS TO NEXT FLT			28	
5	1	2	• LOGISTICS MODULE • AUTO FAB MODULE • PSP TURNTABLE	25.2	182.9	2	

GRUMMAN

G-388

ADVANCED SPACE CONSTRUCTION BASE LEO, 28 1/2° INCLINATION – OPTION 1 A/B, 2B & 3

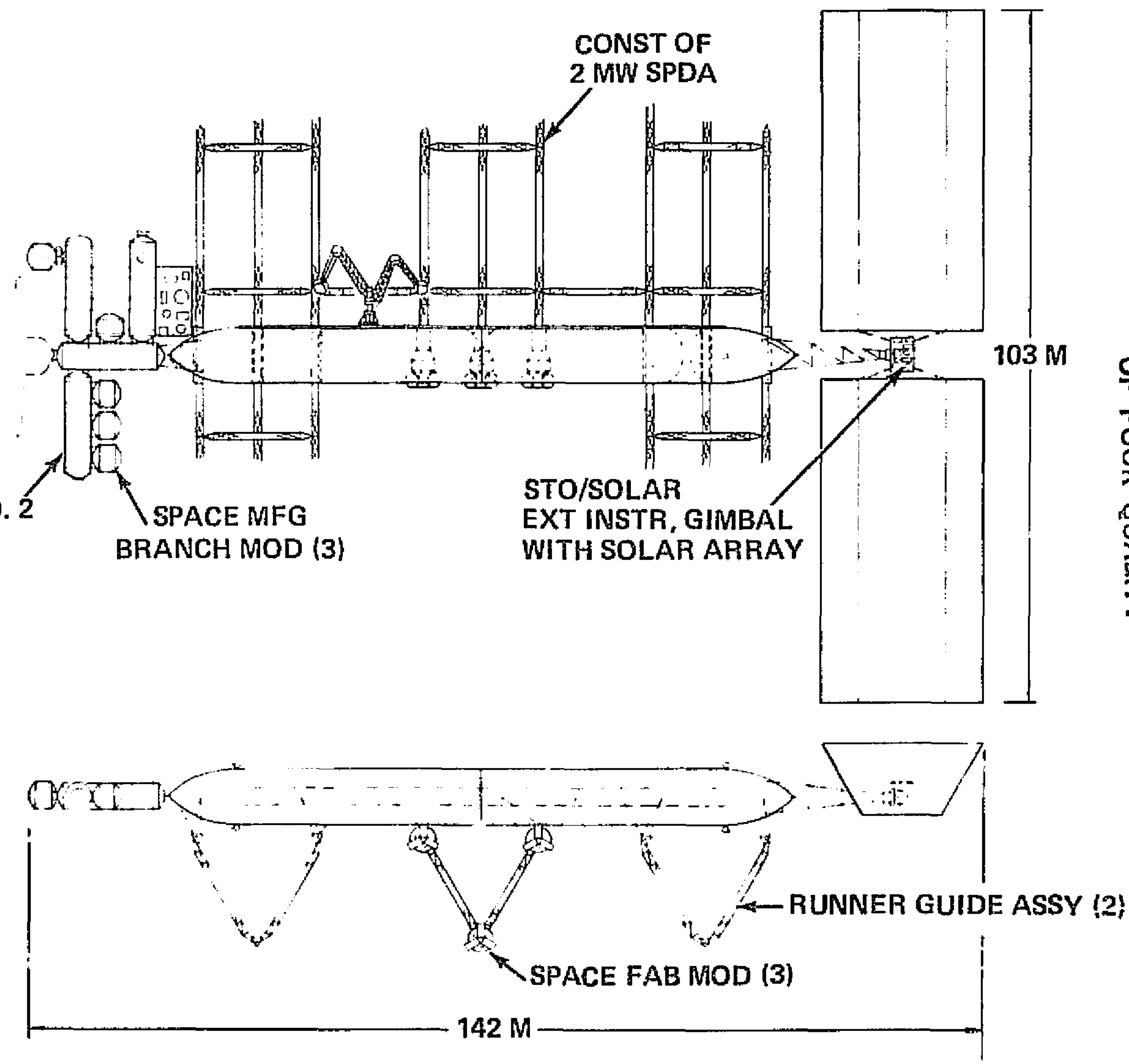
The Advanced SCB is a development of the Initial SCB. To augment the construction capability, two space fabrication modules are added to make a total of three modules in a triangular formation, ready to spit out 1 m beams in their correct relationship for manufacture of the 2 mw SPDA. Two runner guide assemblies are added outboard of the space fabarication modules as part of the SPDA building fixture. Construction of the 2 mw SPDA is described elsewhere. Later in the program additional construction/assembly fixtures will be provided for building the PSP antennas No. 2 and No. 3.

Additional non-construction facilities are, augmented habitation and subsystems for four more crew, an additional laboratory and STO facility. The additional crew men are housed in the habitation module, which can readily accommodate them. The laboratory caters for Manufacturing Development, Life Sciences and STO. The manufacturing development facility includes three small modules external to the main laboratory and are described in the section dealing with space manufacture. Life Sciences experiments are also carried out in this lab. The only STO experiments performed on this base are solar observations. Their associated electronics are housed in the lab but the observation instruments are external and are mounted on a platform between the two wings of the 150 kw SPDA. They gimbal with the array to track the sun. These instruments are within reach of the crane for servicing or film exchange.

G303

ADVANCED SPACE CONSTRUCTION BASE

LEO, 28½ DEG INCL 1A/B & 2B



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SCB WEIGHT SUMMARY ADVANCED CONSTRUCTION BASE

The generation of component level weights, contingency, dry weight, launch weight and total on orbit weight are discussed in some detail elsewhere in this report.

The summary weight statement for the Advanced Construction Base appears on the opposite page.

The Advanced Construction Base consists of the Initial Construction Base plus another laboratory, three space manufacturing branch modules, two additional automatic fabrication modules, SPDA construction guides, and construction and space manufacture materials.

The Initial SCB plus four additional STS payloads, results in an Advanced Construction Base with space manufacture and 2.2 mw SPDA construction capability.

G391T

SCB WEIGHT SUMMARY
ADVANCED CONSTRUCTION BASE

INITIAL SCB PLUS 4 LAUNCHES EXTENDS CAPABILITY TO INCLUDE SPACE MFG AND 2.2 MW SPDA CONST

ITEM	WEIGHT, KG
STRUCTURE	37 593
INDUCED ENVIRONMENTAL PROTECTION	2 349
PROPULSION – RCS	340
PRIME POWER – EPS	6 795
AVIONICS	2 354
ENVIRONMENTAL CONTROL	6 110
PERSONNEL PROVISIONS	4 140
OTHER STRUCTURES	
EXT TANK MODIFICATIONS	5 262
AUTO FABRICATION MODULES	11 073
CONSTRUCTION AIDS/DOCKING	5 766
EPS – 150 KW SPDA MODIFICATIONS	2 730
SPARES	930
CONTINGENCY (25%)	21 361
SUBTOTAL – DRY	106,803
CREW, EXPENDABLES	5 144
PROPELLANT	1 208
CONSTRUCTION MATERIALS	29 605
EXPERIMENTS	12 280
SPACE MANUFACTURE EQUIP	7 507
SPACE MANUFACTURE THROUGHPUT	3 977
TOTAL – LAUNCH	166,524
EXTERNAL TANKS	68 614
150 KW SPDA	25 090
TOTAL – ON ORBIT	260,228

GRUMMAN

G-391

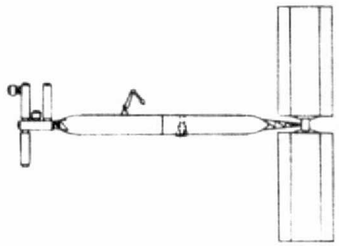
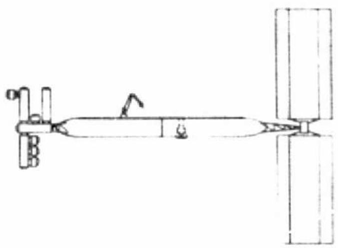
GROWTH FROM INITIAL TO ADVANCED SCB

The evolution from the initial SCB to the advanced SCB requires four flights. The first flight lasting two days, docks to the Subsystem Module (SSM) docking interface. The Cherry Picker/Crane (C-P/C) captures and transports the Manufacturing Development Lab (MDL) from the STS payload bay to its assigned position and the EVA crewmen fix it in place. After checkout, the STS de-orbits. It should be noted that two crewmen from the STS were left on the SCB for a tour of duty.

The second flight, of three days duration, brings up and installs three (3) manufacturing branch modules.

G385T

GROWTH FROM INITIAL TO ADVANCED SCB
SHEET 1 of 2

FLT NO.	CONST CREW STS	CONST CREW SCB	STS PAYLOAD MAJOR ITEMS	STS PAYLOAD WT KG X 10^3	STS PAYLOAD VOL M^3	DAYS	CONFIG
1	1	2	• MANUFACTURING DEVELOPMENT LAB	19.1	228	2	
		5	DAYS TO NEXT FLT			28	
2	1	2	• MANUFACTURING BRANCH MODULES (3)	19.7	183	3	
		5	DAYS TO NEXT FLT			27	

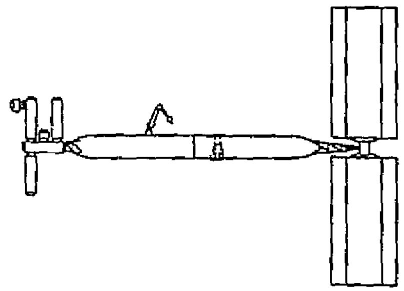
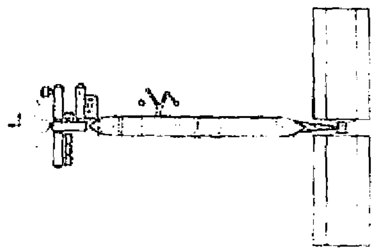
GRUMMAN

GROWTH FROM INITIAL TO ADVANCED SCB

The third flight, lasting two days, delivers a new Logistics Module to replace the existing spent module. The fourth and final flight, lasting four days, delivers two Automatic Fabricating Modules (AFM) to augment the one already in place. After the two AFM's have been installed, the runner guide assemblies (Brought up with AFM's) are transported and fixed in their operating positions. The SCB is now prepared to fabricate the 2.2 mw SPDA.

G386T

GROWTH FROM INITIAL TO ADVANCED SCB
SHEET 2 OF 2

FLT NO.	CONST CREW STS	CONST CREW SCB	STS PAYLOAD MAJOR ITEMS	STS PAYLOAD WT KG X 10^3	STS PAYLOAD VOL M^3	DAYS	CONFIG
3	0	4	• LOGISTICS MODULE	26.2	61	2	
		5	DAYS TO NEXT FLT			28	
4	0	3	• AUTOMATIC BEAM FABRICATING MODULES (2)	18.4	196	4	

GRUMMAN

LEO SCB SUMMARY

CONFIGURATION EVOLUTION REFLECTS

- USE OF EXTERNAL TANKS
- SYMMETRY
- FLIGHT & NADIR DIR TO MINIMIZE CONTROL PROBLEMS & DRAG
- SEPARATE ZONES FOR HABITATION/LABS – CONSTRUCTION – POWER
- GOOD DOCKING CORRIDORS – CONNECTING WITH SPINE TRANSPORTER
- MODULARITY – VERSATILITY – GOOD GROWTH POTENTIAL

BUILD-UP FLIGHTS

- FIVE FOR THE INITIAL SCB – HABITATION STARTS ON THIRD
- FOUR FOR GROWTH FROM INITIAL TO ADV – ADDING SPACE MFG & INCREASING CONST SYS CAPABILITY
- MAJORITY OF THESE FLTS VOL LIMITED BY SMALL MARGIN

OTV-P/C TRANSPORT COSTS LEO TO GEO

Based on the reference data, shown previously, OTV-P/C transport cost has been calculated for various LEO to GEO missions. Note that cargo costs include amortized cost of OTV propellant tanks based on three reuses for STS operations and are expendable when the HLLV becomes available. Turnaround and support costs are based on past Tug and HLLV studies. The cargo cost of transport to GEO is reduced by a factor of ten when the HLLV becomes available. As will be shown later, once this happens the initial orbital depot will be abandoned and a new orbital depot possibly in the same orbit, but a different location will be used for HLLV/OTV operations.

B-317T

OTV-P/C TRANSPORT COSTS LEO TO GEO

CARGO COST/KG TO GEO ARE 10 TIMES MORE WITH STS THAN WITH HLLV

LEO TO GEO MISSN (OTV RECOVERED)		CREW ROTATION	"SMALL" CARGO	"MED" CARGO	"MED" CARGO
LAUNCHER		STS	STS	STS	HLLV-4
PAYLOAD OUT/BACK	(KG x 10^3)	6/5	18/0	70/0	70/0
NO. OF STS COMPATIBLE TANKS		3	3	8	8
COST/FLIGHT		(K$)	(K$)	(K$)	(K$)
OTV TANKS	(3 REUSES)	200	200	540	
	(EXPENDED)				1600
OTV PROPELLANT		120	120	320	320
TANK TO LEO LAUNCH COSTS	(STS 19.3 M/$)	57900	57900	154,400	
(STS COSTS INCL. RETURN)	(HLLV 29 $/KG)				5570
TURN AROUND – (OTV PROPULSION UNIT(S))		500	500	1000	1000
TURN AROUND – (CREW CAPSULE + LOGISTIC MOD.)		300			
SUPPORT – (GROUND & FLT)		3000	3000	4500	4500
TOTAL		62,000	61,720	159,900	12,990
CARGO TRANSPORT(1) $/KG			3400	2300	186

(1) CARGO COST TO LEO EXCLUDED

GRUMMAN

G-317

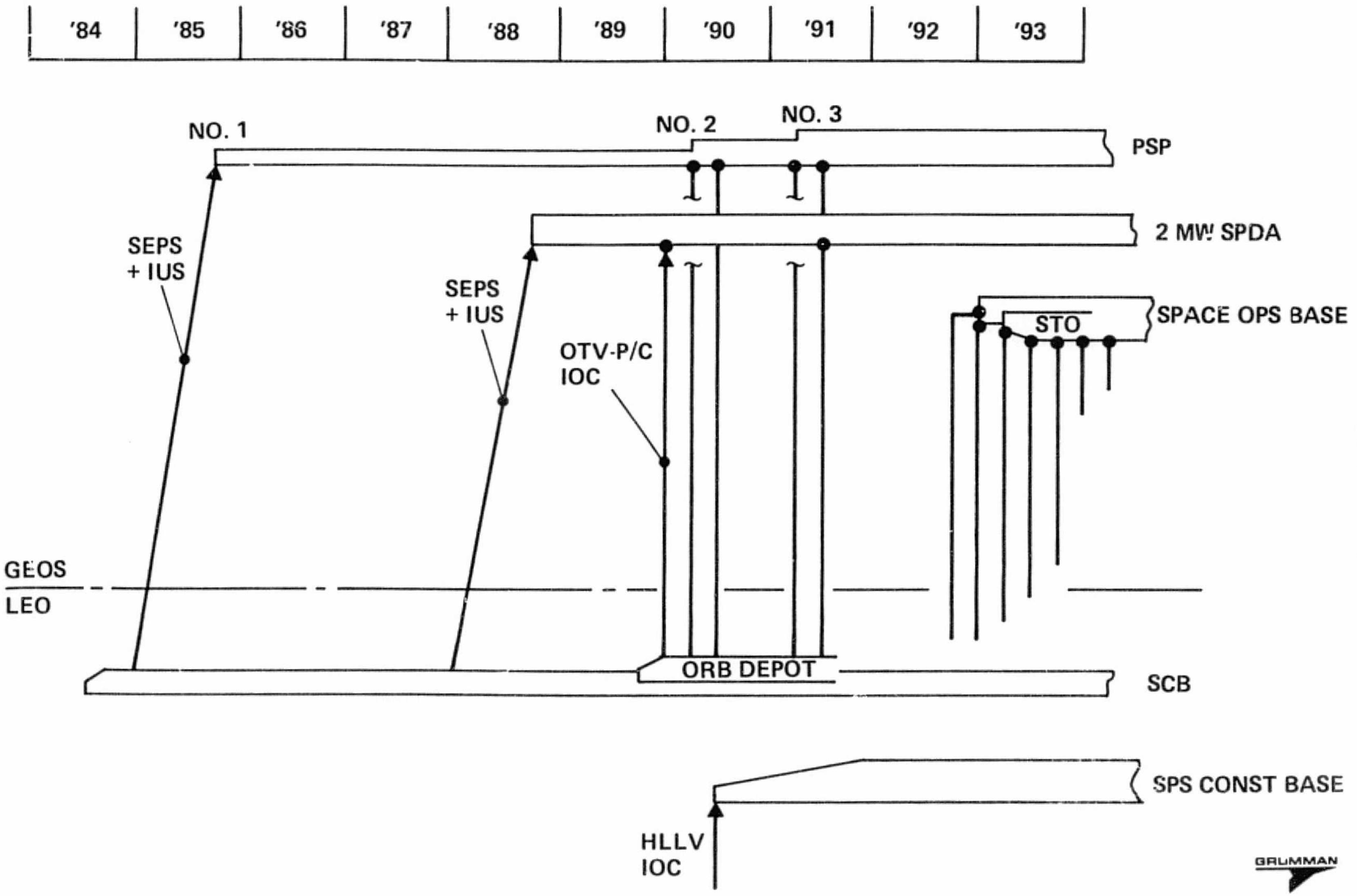
PROGRAM OPTIONS 1A/B & 3 OTV ACTIVITY

The preceding chart shows the dramatic drop in costs when the HLLV is introduced. Operation of the HLLV is considered necessary for construction of the SPS. The SPS Construction Base in LEO will cater for the HLLV. The IOC date of 1995 for the SPS leads to its construction base being built starting mid-1990 with the HLLV operational at that time. Until the SPS Construction Base is operational and capable of servicing the OTV-P/C for transporting men and materials to geostationary orbit, an Orbital Depot will handle the OTV-P/C in LEO. The Orbital Depot is a development of the Space Construction Base started in 1984.

As shown in the figure, prior to man's visits to GEO at the beginning of 1990, transportation of the PSP antenna No. 1 and the 2 mw SPDA to GEO is powered by SEPS + IUS. In 1990 the 2 mw SPDA is scheduled for manned visits and this requires introduction of the OTV-P/C, hence the Orbital Depot. In addition to these manned visits, the OTV also transports the LEO constructed PSP antennas No. 2 and No. 3 to geostationary orbit.

G341T

PROGRAM OPTIONS 1A/B & 3
OTV ACTIVITY



GRUMMAN

G-341

PROGRAM OPTION 2B OTV ACTIVITY

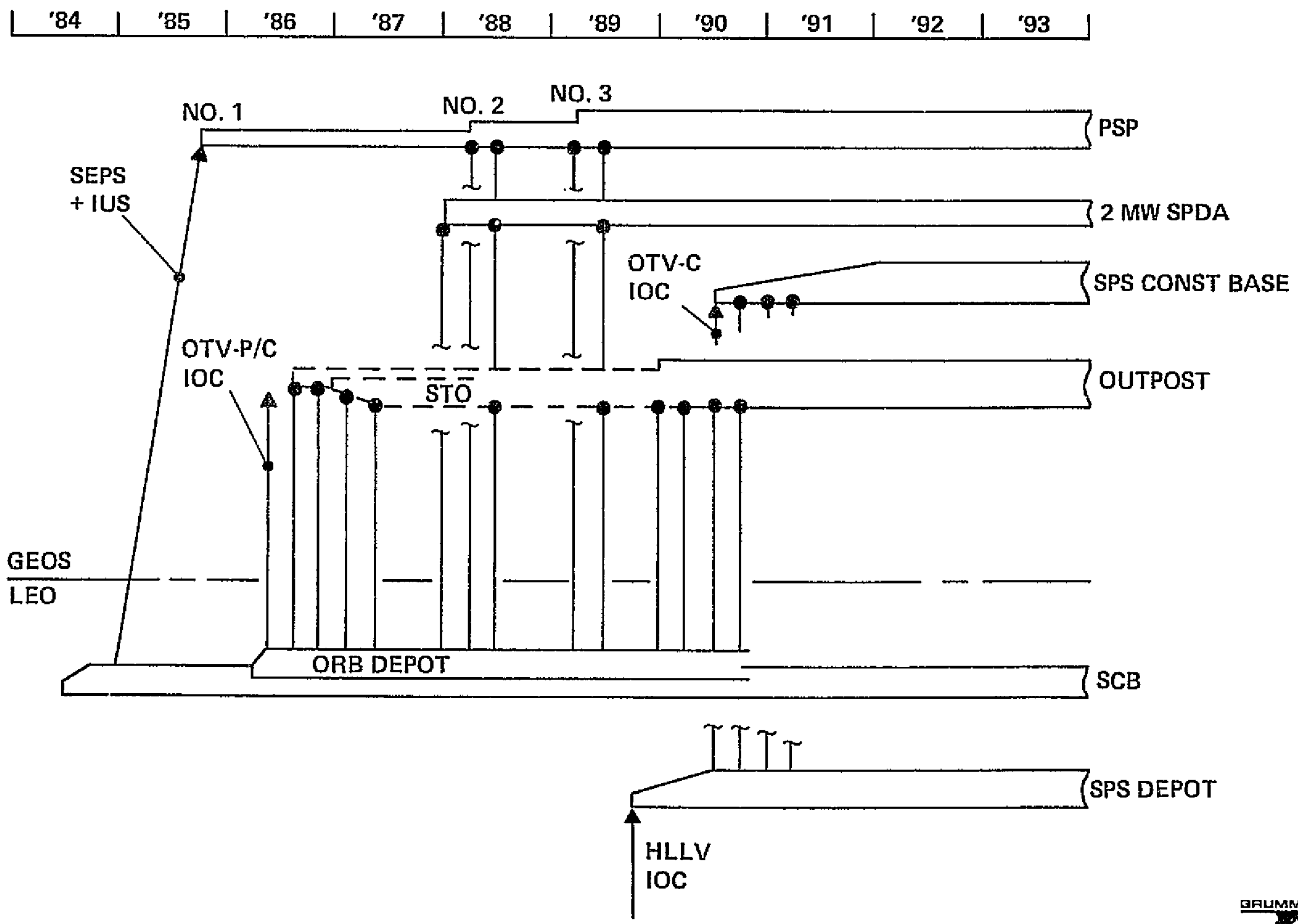
Program Option 2B has manned activity in geostationary orbit starting in 1986. The OTV-P/C is introduced at that time to provide transportation. This, in turn, leads to establishment of the orbital depot in 1986 to handle the OTV in LEO until a LEO SPS construction system depot is established in 1990 to handle the HLLV and SPS associated OTV flights.

As can be seen from the figure, the orbital depot handles sortie flights to the GEO outpost, visits to the 2 mw SPDA and delivers PSP antenna No. 2 and No. 3. PSP antenna No. 1 is delivered to geostationary by a SEPS + IUS combination.

In program Option 2A, OTV activity is similar to Option 2B except that there are about 50% more OTV flights handled by the orbital depot in the 1988 to 1990 time period.

G-340T

PROGRAM OPTION 2B
OTV ACTIVITY



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GRUMMAN

RANGE OF SPS ASSY SITE OPTIONS

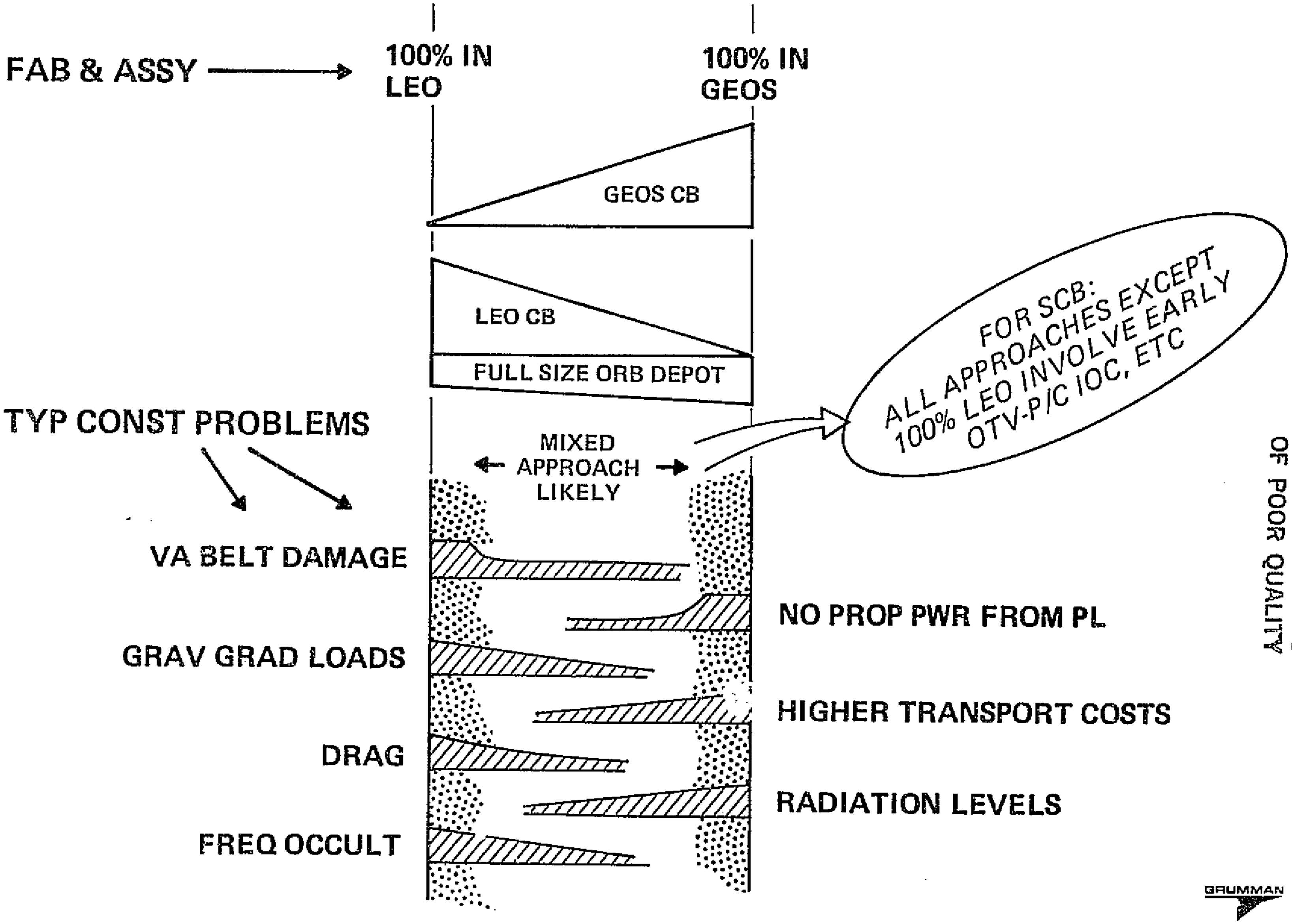
Construction Base sites in low earth orbit and geosynchronous orbit have a strong influence on the program options. Many considerations enter the site selection process. Considering the assembly site for the SPS, present program options locate it in either LEO (Options 1A/B and 3) or geostationary (Options 2A/B). A dedicated SCB located completely in either orbit is impractical and brings such problems as those listed on the chart.

Consider, as an example, the solar array. If the SPS is completed in LEO, then the solar blankets will be operationally in place during transportation to geostationary and subject to deterioration through the Van Allen belt. On the other hand, if the SPS is assembled in geostationary, then the solar array was not available to power the SEPS transportation of the component parts.

Most probably the final solution will be a mixed approach where some construction is performed in low earth orbit and at least final assembly activities will occur in geosynchronous orbit.

G344T

RANGE OF SPS ASSY SITE OPTIONS



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GRUMMAN

G-344

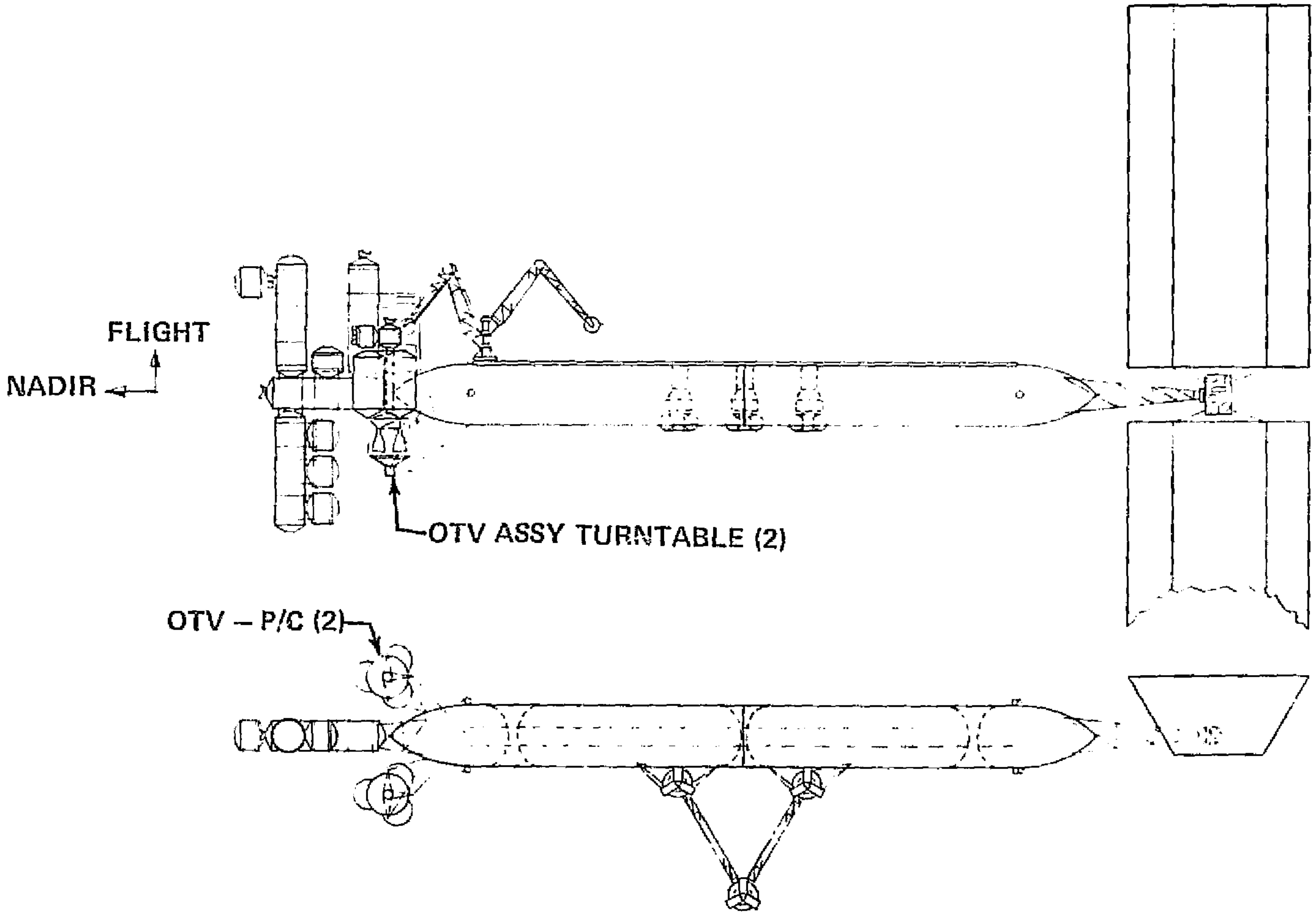
ORBITAL DEPOT LEO, 28½ DEG INCL-OPTION 1A/B, 2A/B & 3

The Orbital Depot is developed from the Advanced SCB. Its prime function is to provide assembly and servicing facilities for OTVs. To this end, two turntables are provided upon which OTVs are assembled. Consider an OTV-P/C being readied for flight to a base in geostationary orbit for resupply and crew rotation. The propulsion unit has been serviced on the assembly turntable using the manned crane manipulators. Shuttle flights then bring up the loaded propellant tanks from earth and the shuttle manipulator has the reach to mate each tank with the OTV spine protruding from the propulsion unit. Forward of the tanks is the crew transportation module which has been docked to the docking ring on Lab No. 1 for crew shirtsleeve ingress and egress and for servicing. The manned crane manipulators transfer the loaded crew module to the OTV assembly area and mount it to the end of the OTV spine, forward of the propellant tanks. A logistics module, loaded on earth and taken to orbit by the shuttle, is then attached to the side of the crew module by the shuttle manipulator.

G305T

ORBITAL DEPOT

LEO, 28½ DEG INCL - OPTION 1A/B, 2A/B & 3



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GRUMMAN

SCB WEIGHT SUMMARY ORBITAL DEPOT

The generation of component level weights, contingency, dry weight, launch weight and total on orbit weight are discussed in some detail elsewhere in this report.

The summary weight statement for the Orbital Depot arrears on the opposite page.

The orbital depot is added to an advanced construction base and has provisions for docking, assembling, repairing and maintaining two Orbital Transfer Vehicles. The OTV is a cryo tug for transferring personnel and cargo from low earth orbit to geostationary orbit and consists of propellant tanks, propulsion unit, crew module and payloads module.

Two fully fueled OTV's could be at the SCB at any given time. The weight statement shows the SCB-Orbital Depot weight with two full up OTV's that weight 152,200 kg.

G393T

SCB WEIGHT SUMMARY
ORBITAL DEPOT

OTV/PC'S ARE BIGGEST WEIGHT DRIVER

ITEM	WEIGHT, KG
STRUCTURE	40 313
INDUCED ENVIRONMENTAL PROTECTION	5 349
PROPULSION – RCS	340
PRIME POWER – EPS	7 075
AVIONICS	2 354
ENVIRONMENTAL CONTROL	6 110
PERSONNEL PROVISIONS	4 140
OTHER STRUCTURES	
EXT TANK MODIFICATIONS	5 262
AUTO FABRICATION MODULES	11 073
CONSTRUCTION AIDS/DOCKING	5 030
EPS – 150 KW SPDA MODIFICATIONS	2 730
SPARES	930
CONTINGENCY (25%)	22 677
SUBTOTAL – DRY	113,383
CREW, EXPENDABLES	5 144
PROPELLANT	2 416
CONSTRUCTION MATERIALS	23 605
EXPERIMENTS	12 280
SPACE MANUFACTURE EQUIP	7 507
SPACE MANUFACTURE THROUGHPUT	3 977
OTV/PC (2)	152 200
OTV SPARES	5 000
TOTAL – LAUNCH	325,512
EXTERNAL TANKS	68 614
150 KW SPDA	25 090
TOTAL – ON ORBIT	419,216

GRUMMAN

G-393

ORBITAL DEPOT SUMMARY

PROGRAMATIC

SPS ASSD 100% IN LEO

OPTION 1A/B-3

OTV-P/C IOC-89
2-3 FLTS/YEAR

SPS ASSD WHOLLY OR PARTIALLY IN GEOS

OPTION 2A/B

OTV-P/C IOC - 85/86

3-5 FLTS/YEAR

- MAJOR REDUCTION OF OPERATING COST WHEN HLLV INTRODUCED – ORBITAL DEPOT SITE MAY THEN SWITCH

CONFIG

- MANNED ORBITAL FLTS REQUIRE BACK-UP OTV-P/C NEAR TO FLT READINESS
- SYMMETRICAL MODULAR TWIN PAD DEPOT 7500 KG DRY
- TWO LAUNCH-READY CREW ROTATIONS OTV-P/C 152,200 KG

GRUMMAN

G-416

BASE: LEO HIGH INCLIN – OPTION 3

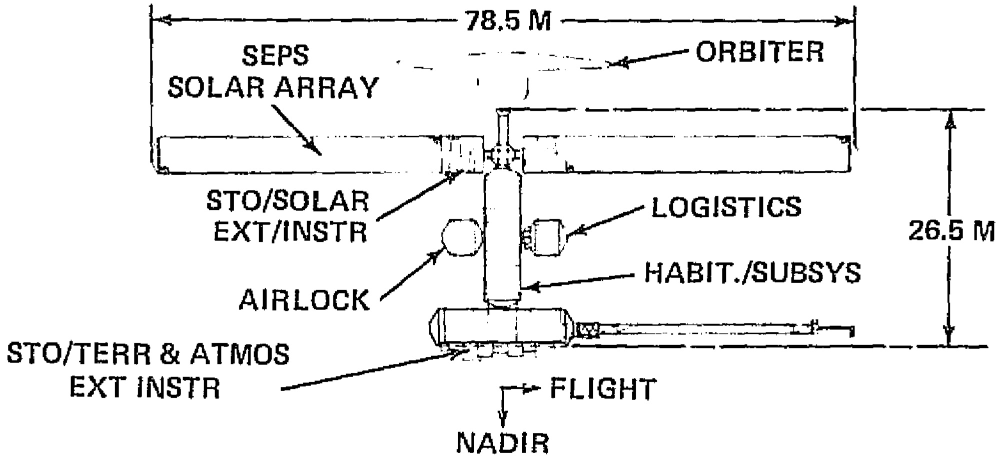
That part of the STO mission dealing with terrestrial, atmospheric and magnetospheric observations cannot be performed satisfactorily in 28½ degrees inclination, LEO. To provide this coverage, program Option 3 has a base in high inclination, LEO.

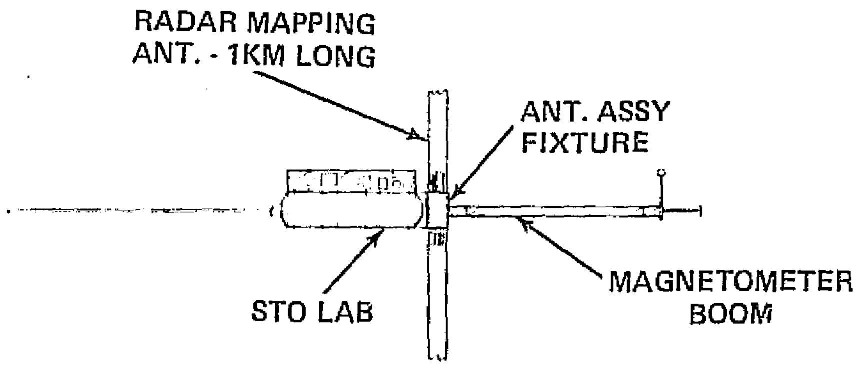
The base, shown in the figure, provides a combined habitation and subsystems module catering for a crew of three and station operations. The logistics module carries supplies for 90 days and is attached to the habitation module. Exchange of full and empty logistics modules is effected by the resupply shuttle manipulator. An external airlock is provided for crew EVA. Power is supplied by a two winged SEPS solar arrays mounted on a two axis gimbal to track the sun. Docking for the shuttle is provided outboard of the solar array mount with an interconnecting tunnel to the habitation module for shirtsleeve crew transfer.

A laboratory module houses internal instruments, which scan the earth, and experiment associated electronics. Attached to the lab is a platform which mounts external instruments to look along the local vertical for terrestrial and atmospheric observations. A magnetometer boom extends forward of the lab in the direction of flight. STO solar observation instruments are external and are mounted on a platform adjacent to the solar array. They gimbal on common axes with the array to track the sun. An earth resources antenna for radar mapping is also carried on the base.

G302T

BASE:
LEO HIGH INCLN – OPTION 3





C-2

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GRUMMAN

G-302

SCB WEIGHT SUMMARY STO AND EARTH RESOURCES LAB

The generation of component level weights, contingency, dry weight, launch weight and total on orbit weight are discussed in some detail elsewhere in this report.

The summary weight statement for the STO and Earth Resources Laboratory appears on the opposite page.

The STO lab is a three module SCB that is launched to, and assembled in, a high inclination low earth orbit. Exact inclination has not yet been chosen. The STO lab consists of a combination Subsystem/Habitation module, a laboratory, a logistics, module, a SEPS power source, and mission hardware and expendables. An airlock is provided internal to the Subsystem Habitation Module.

By far the largest weight driver in this configuration is the 33,000 kg of STO experiments.

G394T

SCB WEIGHT SUMMARY
STO & EARTH RESOURCES LAB

STO EXPERIMENTS ARE BIGGEST WEIGHT DRIVER

ITEM	WEIGHT, KG
STRUCTURE	16 735
INDUCED ENVIRONMENTAL PROTECTION	987
PROPULSION – RCS	340
PRIME POWER – EPS	2 205
AVIONICS	1 804
ENVIRONMENTAL CONTROL	3 329
PERSONNEL PROVISIONS	2 084
OTHER STRUCTURES	
EXT TANK MODIFICATIONS	–
AUTO FABRICATION MODULES	–
CONSTRUCTION AIDS/DOCKING	824
EPS – SEPS MODIFICATIONS	500
SPARES	575
CONTINGENCY (25%)	7 346
SUBTOTAL – DRY	36 729
CREW, EXPENDABLES	2 032
PROPELLANT	1 208
CONSTRUCTION MATERIALS	–
EXPERIMENTS	35 130
SPACE MANUFACTURE EQUIP	–
SPACE MANUFACTURE THROUGHPUT	–
SEPS POWER SUPPLY	1 689
TOTAL – LAUNCH	76 788
EXTERNAL TANKS	–
150 KW SPDA	–
TOTAL – ON ORBIT	76 788

GRUMMAN

G-394

SPACE CONSTRUCTION BASE GEOSTATIONARY ORBIT – OPTION 2A

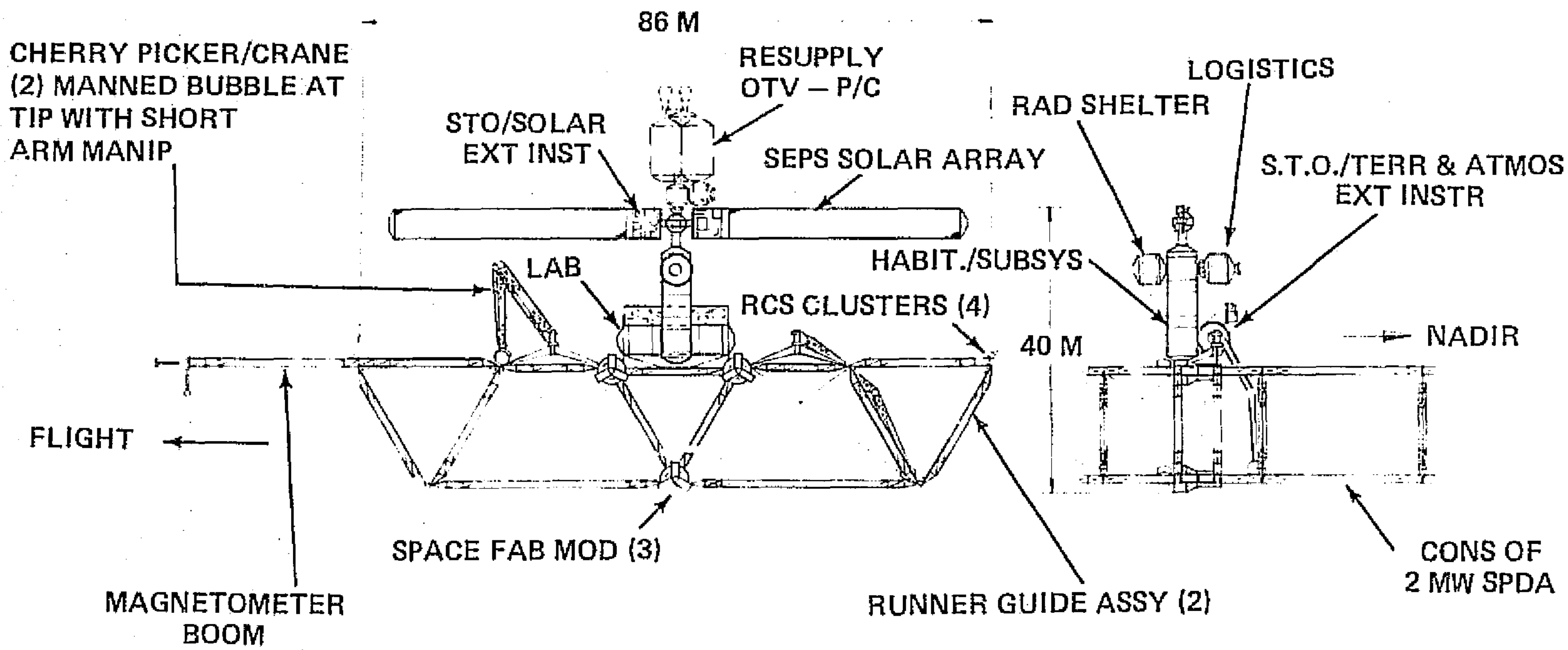
This program option requires that the 2 mw SPDA be constructed in geostationary orbit. The construction base is built in LEO with the help of the Initial Construction Base then transported to its geostationary operational orbit by OTV-P/C.

The construction part of the base is configured primarily to build the 2mw SPDA. Later, the PSP antennas No. 2 and No. 3 are built and will require such additional facilities as turntables. Construction of the 2 mw SPDA follows the procedures described elsewhere for construction by the LEO Advanced Construction Base. This base provides similar space fabrication modules and runner guides. There are two, fixed mount, crane facilities each comprising an articulated arm with a pressurized bubble at its tip. Each bubble houses a shirtsleeve crew member operating short arm manipulators to make structural joints, etc. The mainpualtor docks the bubble to the habitation module for the operator to "go home". Power is provided by a SEPS two winged solar array mounted on a two axis gimbal to track the sun.

A combined habitation and subsystems module provides the necessary accommodations and subsystems for a crew of three and for station operations. A laboratory module houses STO internal instruments and electronics, some life sciences capability to monitor the performance of the crew and equipment for SPS development and construction test samples. An external platform mounts STO terrestrial and atmospheric instruments to look along the local vertical. STO solar instruments are mounted on another platform adjacent to the solar arrays which gimbals with the arrays to track the sun. Docking of the OTV-P/C for crew rotation and logistics resupply is provided outboard of the solar array mounts with a connecting tunnel to the habitation module for shirtsleeves crew transfer. The full and empty logistics modules are exchanged by the cranes. A shelter is provided for crew protection from solar flare radiation.

G301T

SPACE CONSTRUCTION BASE
GEOSTATIONARY ORBIT - OPTION 2A



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GRUMMAN

G-301

SCB WEIGHT SUMMARY GEO CONSTRUCTION BASE

The generation of component level weights, contingency, dry weight, launch weight and total on orbit weight are discussed in some detail elsewhere in this report.

The summary weight statement for the Geostationary Space Construction Base appears on the opposite page.

The GEO SCB is assembled in low orbit and transported to geostationary orbit. The base consists of a combination Subsystem/Habitatility Module, an airlock, a geos/laboratory, a logistics module SEPS power source, construction materials and expendables.

The largest single source of weight aboard this SCB is the Solar Territoral Observatory experiments. The STO experiments are estimated to weigh 33,000 kg.

G392T

SCB WEIGHT SUMMARY
GEO CONSTRUCTION BASE

STO EXPERIMENTS ARE BIGGEST WEIGHT DRIVER

ITEM	WEIGHT, KG
STRUCTURE	18 860
IND ENVIRON PROT (INCL SOLAR STORM SCHELTER)	9 774
PROPULSION — RCS	340
PRIME POWER — EPS	2 310
AVIONICS	1 812
ENVIRONMENTAL CONTROL	3 394
PERSONNEL PROVISIONS	2 179
OTHER STRUCTURES	
EXT TANK MODIFICATIONS	4 186
AUTO FABRICATION MODULES	11 073
CONSTRUCTION AIDS/DOCKING	1 580
EPS — SEPS MODIFICATIONS	500
SPARES	575
CONTINGENCY (25%)	14 146
SUBTOTAL — DRY	70,729
CREW, EXPENDABLES	2 122
PROPELLANT	1 208
CONSTRUCTION MATERIALS	29 605
EXPERIMENTS	35 130
SPACE MANUFACTURE EQUIP	—
SPACE MANUFACTURE THROUGHPUT	—
SEPS POWER SUPPLY	1 689
TOTAL — LAUNCH	140,483
EXTERNAL TANKS	—
150 KW SPDA	—
TOTAL — ON ORBIT	140,483

GRUMMAN

G-392

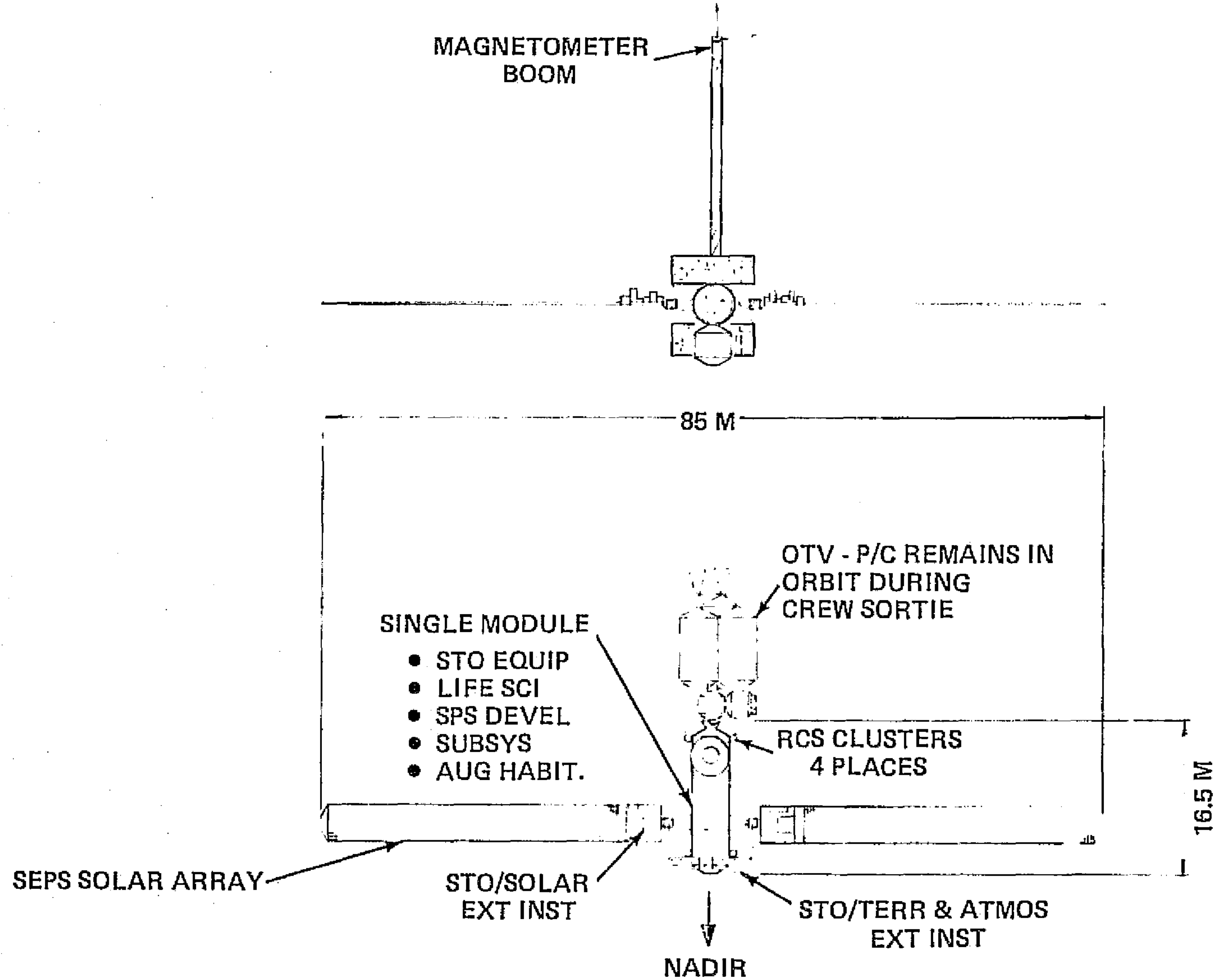
OUTPOST GEOSTATIONARY ORBIT – OPTION 2B

Program Option 2B calls for the SPS to be built in geostationary orbit. The effects on man of the environment at this orbit will be an input into the "go/no go" decision to pursue this option. The Outpost provides a relatively low cost housing for man to check these effects over a time period.

The manned mission is a long term sortie mission with three men transported in an OTV-P/C which remains in geostationary orbit attached to the Outpost for the duration of the men's stay. The crew transportation module and the Outpost module provide, between them, relatively spartan habitation and subsystems facilities. A logistics module remains attached to the crew module. The Outpost module also provides some life sciences capability to check the crew performance and condition, some mechanical tasks oriented towards SPS development to calibrate crew performance and housing for any STO internal equipment which could usefully be put aboard the Outpost. External to the module is a platform to mount instruments for STO/terrestrial and atmospheric experiments. A magnetometer boom extends from the platform. Adjacent to the solar arrays and mounted on the same gimbal is another platform which mounts STO/solar instruments. Power is supplied by a SEPS two winged array mounted on a single axis gimbal. The other gimbal axis necessary to track the sun is provided by rotation of the Outpost about its local vertical axis.

G306T

OUTPOST
GEOSTATIONARY ORBIT OPTION 2B



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GRUMMAN

G-306

SCB WEIGHT SUMMARY GEO OUTPOST

The generation of component level weights, contingency, dry weights, launch weight and total on orbit weight are discussed in some detail elsewhere in this report.

The summary weight statement for the Geostationary Outpost appears on the opposite page.

The GEOs outpost is a minimal, self-support, tended space base. It consists of a single module, SEPS Solar Power, and some experimentation. The single module houses the subsystems and experiments and provides habitable volume for the crew when visited by sortie flights.

G395T

SCB WEIGHT SUMMARY
GEO OUTPOST

MINIMAL, SELF SUPPORTING, TENDED SPACE BASE

ITEM	WEIGHT, KG
STRUCTURE	6 241
INDUCED ENVIRONMENTAL PROTECTION	431
PROPULSION – RCS	340
PRIME POWER – EPS	1 525
AVIONICS	1 413
ENVIRONMENTAL CONTROL	1 774
PERSONNEL PROVISIONS	652
OTHER STRUCTURES	
EXT TANK MODIFICATIONS	–
AUTO FABRICATION MODULES	–
CONSTRUCTION AIDS/DOCKING	422
EPS – SEPS MODIFICATIONS	500
SPARES	300
CONTINGENCY (25%)	3 400
SUBTOTAL – DRY	16 998
CREW, EXPENDABLES	325
PROPELLANT	1 208
CONSTRUCTION MATERIALS	–
EXPERIMENTS	6 000
SPACE MANUFACTURE EQUIP	–
SPACE MANUFACTURE THROUGHPUT	–
SEPS POWER SUPPLY	1 689
TOTAL – LAUNCH	26,220
EXTERNAL TANKS	–
150 KW SPDA	–
TOTAL – ON ORBIT	26,220

GRUMMAN

G-395

INTERNAL VOLUME REQUIREMENTS – PRELIMINARY MODULE ALLOCATIONS

A standard full size module (3.86 m I D X 15.75m) has a free air volume of approximately 167 m^3. Effective partitioning of these modules will provide adequate volumes for habitation, equipment and experiments. A habitation module provides approximately 100 m^3 for crew living and activity (central aisle included) with 25 m^3 available for equipment. A subsystem module provides approximately 85 m^3 for equipment and 40 m^3 for crew activity/living (central aisle included).

Eight m^3 is used to determine volume requirements per crew man and a 100 percent packaging factor is used for equipment installations.

The gross values on accompanying table indicate that a full sized HAB module, subsystem module and one or two LAB modules will meet requirements for all LEO, 28 ½° missions. For the LEO, Hi-inclination and GEO synchronous Option 2A mission the required function can be packaged in one or two modules. For the GEO 2B mission one module could be used.

G-376T

INTERNAL VOLUME REQUIREMENTS

PRELIM MODULE ALLOCATIONS

- *2A ADV MIGHT LOSE A MODULE*
- *3 – HI-INCL MIGHT GAIN ONE*

	LEO						GEOS	
	28½°					HI-INCL	0°	
PROG OPTION	INITIAL ALL	ADV 1A/B	ADV 2A	ADV 2B	ADV 3	3	2A	2B
CREW SIZE	5	10	8	11	10	3	3	(3)
HAB – (A)	40 0.5	80 0.9	64 0.7	88 1.0	80 0.9	24 0.3	32 0.3	(0.3)
SUB – (B)	25 0.6	35 0.8	35 0.8	35 0.8	35 0.8	24 0.6	24 0.6	24 0.6
LABS – (B)								
STO	6	6	—	—	—	20	20	10
LIFE SC	8	18 } 0.8	18 } 0.7	18 } 0.7	18 } 0.7	—	12	6
MDL	— } 0.7	11	11	11	11	— } 0.4	} 1.1	} 0.4
SPS DEV	10	20 } 0.6	18 } 0.5	20 } 0.6	20 } 0.6	—	10	3
CONST	8	8	4	8	8	—	8	—

LEGEND: L H FIG. IN BOX ~ M^3 REQD

R H FIG. IN BOX ~ FRACTION OF MODULE REQD

NOTE: (A) 1 MODULE PROVIDES 91 M^3 OF HABITATION VOL

(B) 1 MODULE PROVIDES 44 M^3 OF COMPONENT VOL

GRUMMAN

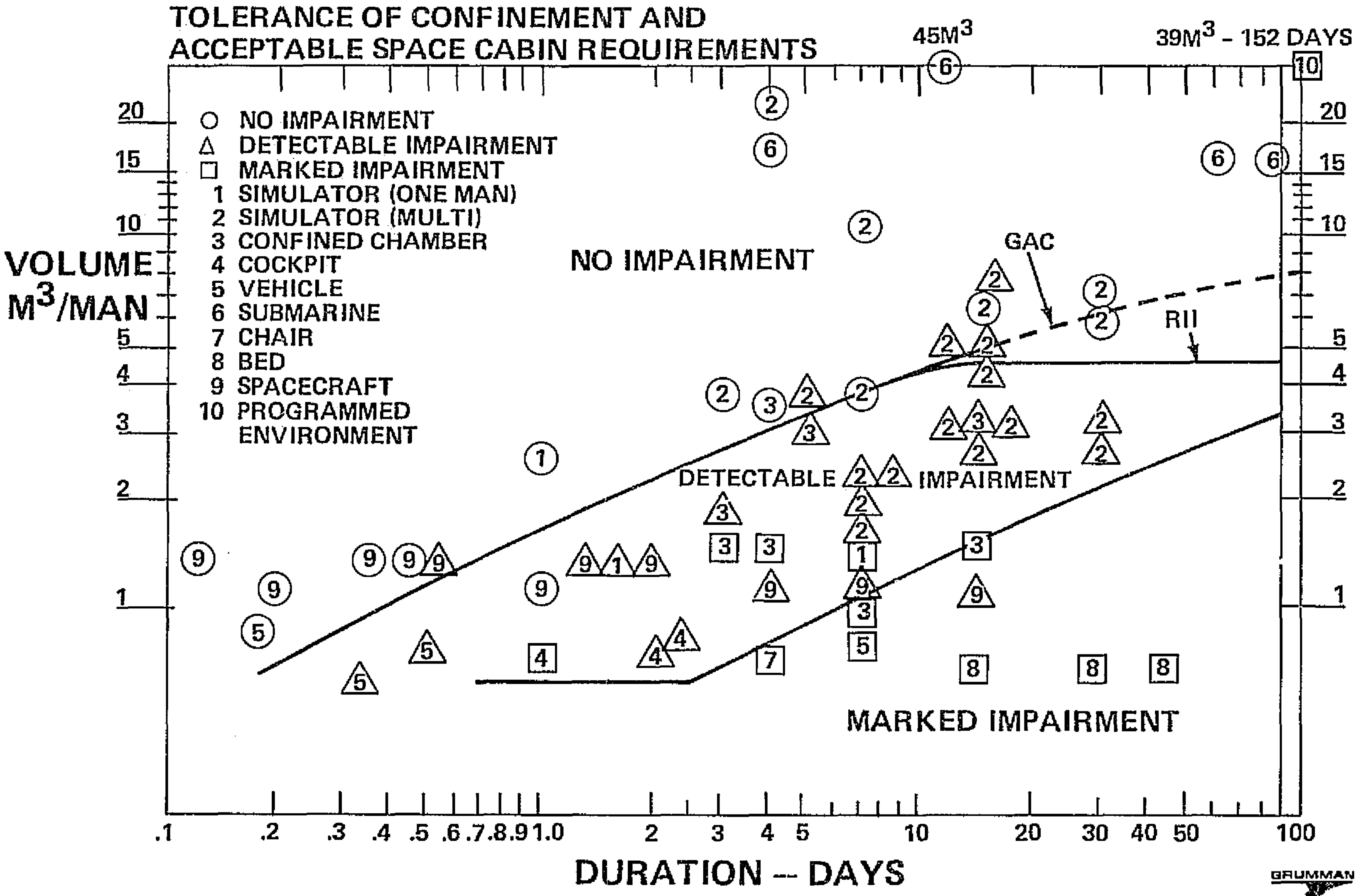
G-376

FREE VOLUME -- DURATION TOLERANCE FACTORS IN CONFINEMENT

The adjacent graph is a modification to one contained in the Rockwell International Report, PD76-20, December, 1976. The upper curve was changed to show a volume/man increase to 8 m^3 at 100 days rather than the flat curve of 4½ m^3 from the 10 to 100 day area. It is felt that the data points reflect a continued volumetric increase per man with time and not a constant volume requirement. The slope of the curve as modified herein, parallels the information contained in the latest MSFC in-house study.

Preliminary calculations indicate that 8 m^3/man is a minimum requirement for a crew member on a 90 day mission in space. This value falls on the curve between detectable impairment and no impairment. It is recommended that habitability layouts reflect a value higher than 8 m^3/man.

FREE VOLUME – DURATION TOLERANCE FACTORS IN CONFINEMENT



G-325

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SCB VOLUME ESTIMATES

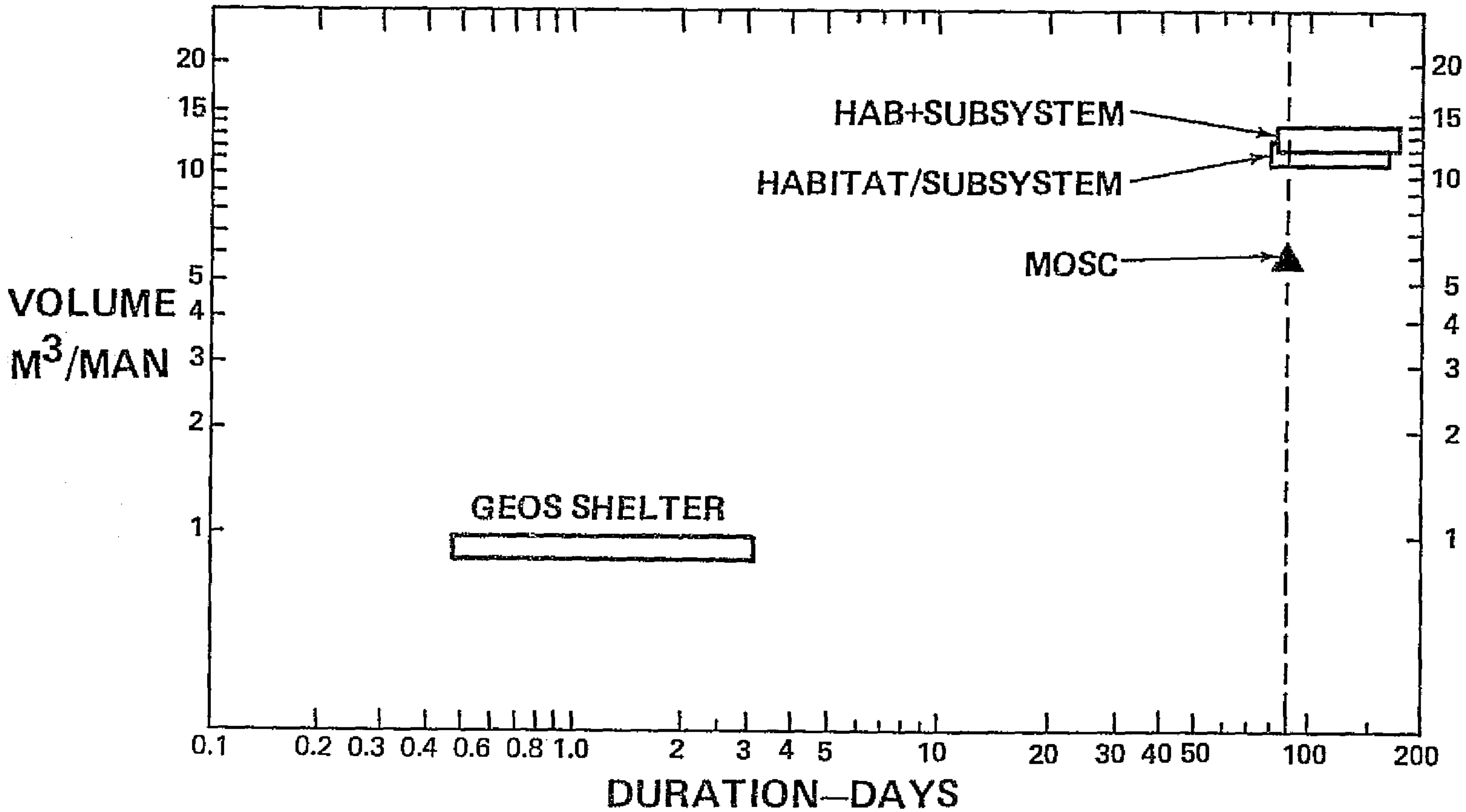
The summation of volumes allotted for crew quarters, commanders quarters/office, waste management, personal hygiene, galley/wardroom area, exercise area, rest and recreation area and sick bay are used to determine crew volumetric requirements. In the configurations shown the value is close to 8 m^3 per man. With the free volume provided by the wide central and branch aisles included, this value increases to approximately 13 m^3 per man. The HAB/SUB combined modules provide slightly less volume (12 m^3).

The SCB can utilize the additional volume afforded by the aisles/passageways in providing more living area for the crew on long duration flights.

The GEO shelter volume per man is at the low end of the curve. For the short duration mission the accommodations provided are similar to small aircraft with inherent comfort and operation impairment penalties.

G324T

SCB VOLUME ESTIMATES



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GRUMMAN

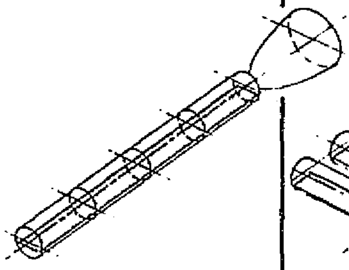
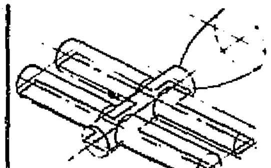
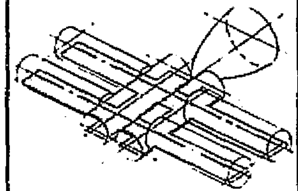
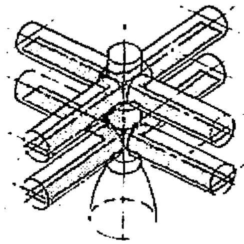
G-324

MODULE ARCHITECTURAL OPTIONS

Standardized modules can be assembled in all configurations shown. The linear, planar and twin spine planar arrangements have common baseline features while the pagoda requires a customized central spine. For a moderate sized space construction base, the first three configurations shown have the better initial and growth possibilities.

The baseline arrangement chosen is the planar configuration. It provides for an 11 man habitation module with a central spine subsystem module. An airlock, logistic module and up to three laboratory modules can be added with ease.

MODULE ARCHITECTURAL OPTIONS

	LINEAR	PLANAR (CURRENT BASELINE)	TWIN SPINE PLANAR	PAGODA
				
• STIFFNESS/STRENGTH	LIMITED	√	√	√
• EXT. LOGIST/MOD HANDLING	NEEDS RAILS	√	√	RESTRICTED
• INTERNAL CIRCULATION	POOR	√	√	COMPLEX
• ONE FLOOR LEVEL	√	√	√	SEVERAL
• USEABLE VOLUME/MODULE	√	LOSSES AT BRANCHES		SEVERE LOSSES

GRUMMAN

G-375

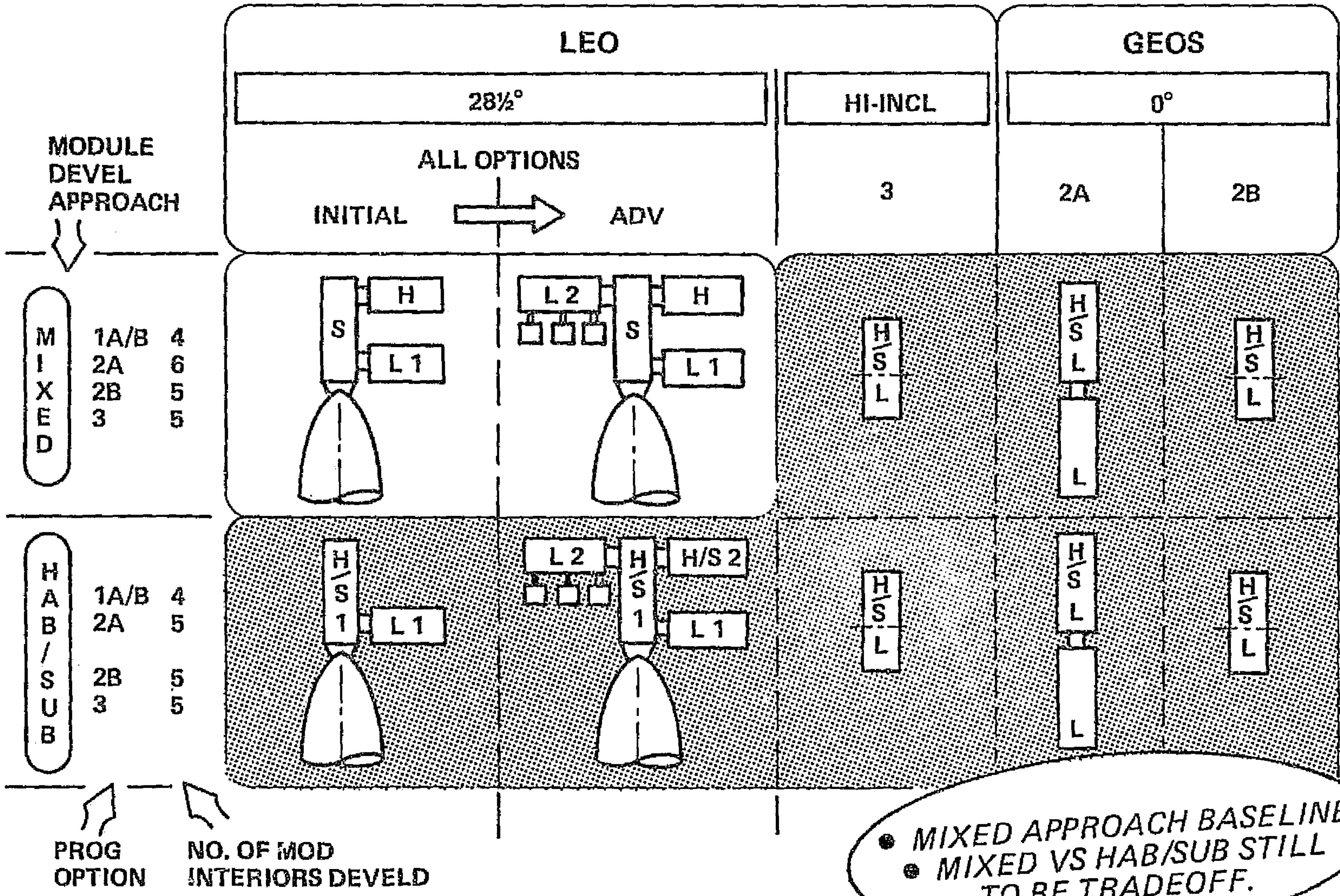
INTERIOR MODULES – HOW MANY MODULES

Two approaches for packaging crew and equipment are under consideration. One is to locate the crew and their supporting facilities in one module called the habitat and places the hardware/equipment in a second module called the subsystem. The mixed approach is to place as many crew members with supporting hardware and subsystem equipment in one module. When required a second habitat/subsystem module is added to the SCB.

The first approach provides a more efficient SCB, but in the initial phase of operation requires one more module than the HAB/SUB configuration. In the advance phase of operation, the mixed and HAB/SUB arrangements require the same number of modules. However, the mixed version provides a better configuration.

The LEO hi-inclination and GEO synchronous modes lend themselves to the HAB/SUB arrangement.

HOW MANY MODULES?
INTERIOR ACCOMMODATIONS



- MIXED APPROACH BASELINE
- MIXED VS HAB/SUB STILL TO BE TRADEOFF.

GRUMMAN

G-377

LEO - SCB - CIRCULATION, PASSAGES AND OPENING SIZES

The arrangement shown is baseline for this reporting period. The planar architectural configuration utilizes the subsystem module as the central spine for initial SCB construction. The subsystem, habitat and lab modules are all the same size (4.06m dia X 15.75 m long). Each module has an identical core size, and configuration, with five branch cylinders. A branch dia of 1.65 m is used to mechanically attach additional modules. With allowance for bolted connections, seals,electrical wiring and ducting interfaces a 1.0 m X 1.25 m opening between modules is achieved. The core module has either a branch type attachment, international docking ring, or dome end affixed at its ends.

This configuration produces a standardized module that can be utilized for all types of internal functions.

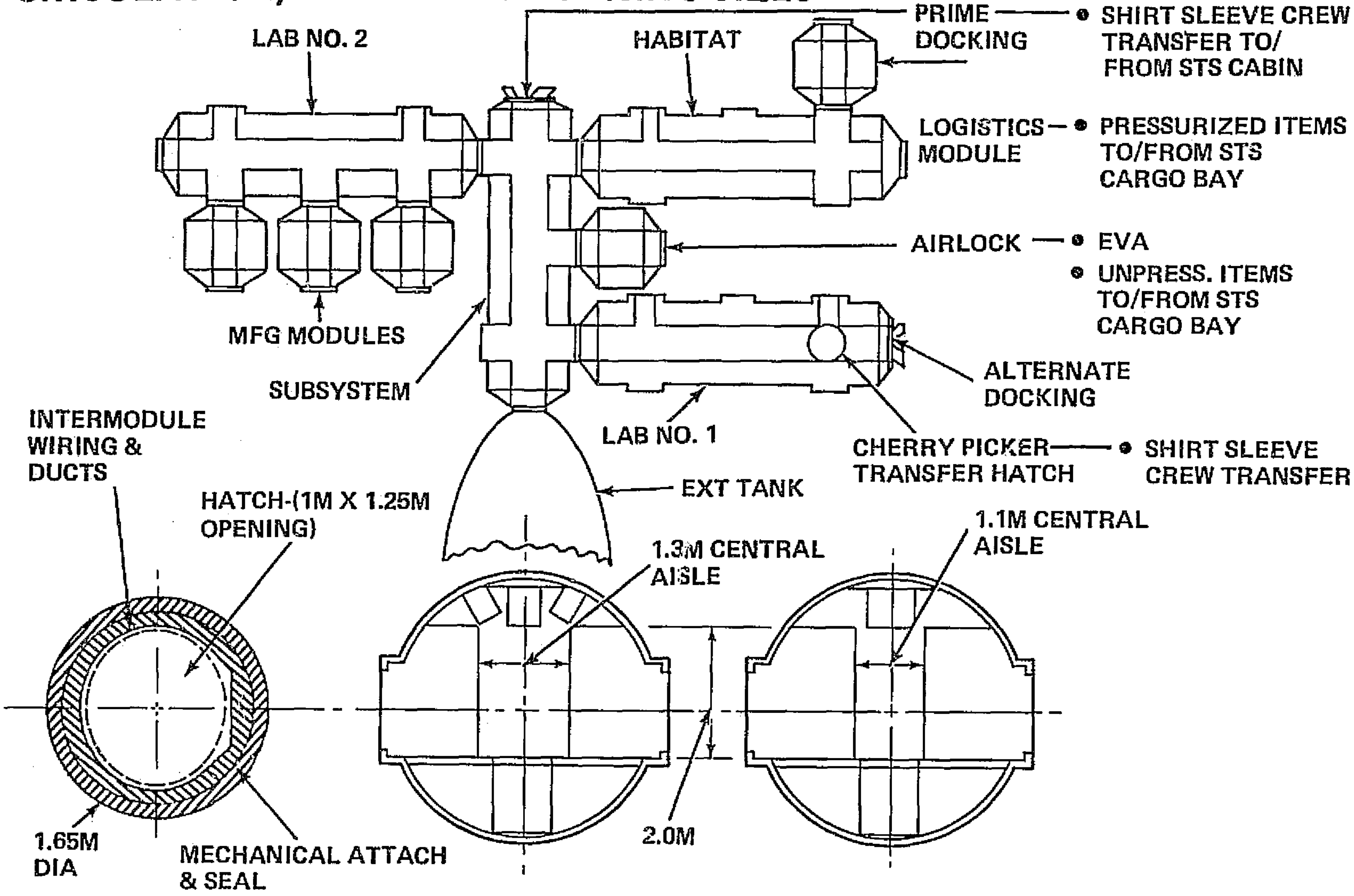
The cross sections of the HAB, SUB system and LAB's are very similar, the main difference being the aisle width. Commonality of modules is a design goal for minimizing development costs.

The airlock and logistic modules are shortened versions of the standard modules and contain many design commonality features of the larger units.

The circulation through the SCB utilizes a 1.1 m aisle in this wing modules and a 1.3 m aisle in the core module. A hatch located at each branch permits isolation of a module if required by crew operation or emergency conditions.

G-398T

LEO SCB
CIRCULATION, PASSAGES & OPENING SIZES



TYPICAL INTERMODULE OPENING – (8 PLCS)

SUBSYSTEM CROSS SECT (SPINE)

HANITAT/LABs CROSS SECT (LATERALS – 3 PLCS)

GRUMMAN

HABITATION MODULE

This module attached to the subsystem module can support 11 men for 90 days. A commander's quarters/office plus nine crew quarters are provided. For the short time span of the lengthly mission when an eleventh man is required, the EMU compartment is converted to a crews quarter. The five EMUs are relocated to the subsystem module on a temporary basis. When the eleventh man departs this volume is reconfigured as an EMU stowage facility.

A waste management compartment and personal hygiene compartment, with shower, are located at the end of the module near the subsystem module, thus providing maximum access to all areas of the SCB. The galley/wardroom located at the other end is at the farthest extremity of the central spine, thus providing an area of minimum activity. A hexagon shaped table with plug in food trays provide eating facilities for six crew men at one sitting. Providing for all 11 men at one sitting would be volume consuming. The galley/freezer/chiller are contemplated to be skylab hardware.

The exercise center is located in the dome end portion of the module. Crew members can utilize the facilities without impairing movement of other crew members on duty.

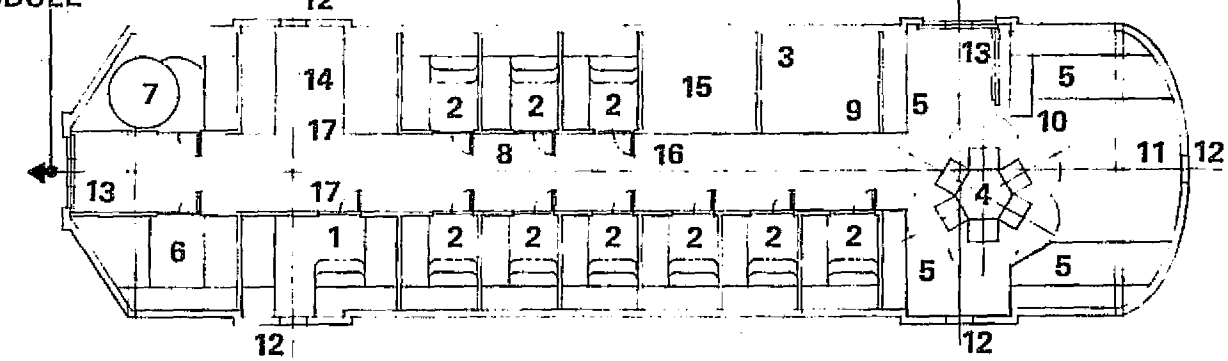
A logistic module (LM) attached to the branch near the galley minimizes traffic when transferring food, waste and personal equipment between the modules. The L/M is mechanically fastened to the branch, thus providing a 1 m X 1.25 m opening rather than an 0.82 m dia produced with the international docking ring.

ECLS, electronics, navigation and guidance, EPS, etc. equipment is located in a floor to ceiling compartment 0.8 m long. Equipment is stowed in full length overhead lockers. A central aisle below the floor provides access to approximately 25 m^3 of additional equipment installation.

Four 50-cm dia windows provide visibility to the outside environment.

G-327T

HABITATION MODULE



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CREW LIVING	CREW SUPPORT	MISSION SUPPORT
1. CMDRS QTRS/OFFICE	9. EMU (5)	14. CONTROLS & DISPLAYS
2. CREW QUARTERS (9)	10. REST & RECREATION EQUIP	15. ELECTRONICS, ECS, ETC.
3. CREW QUARTER(1)-WHEN RQ'D	11. EXERCISE CENTER	16. STOWAGE (CEILING)
4. DINING AREA	12. 50 CM WINDOW (4)	17. SUBSYSTEMS (BELOW FLOOR)
5. GALLEY/FREEZER/CHILLER	13. HATCH – 1.0 x 1.25M OPEN. (2)	
6. WASTE MANAGEMENT		
7. PERSONAL HYGIENE		
8. AISLES/PASSAGEWAYS – 1.1M		

GRUMMAN

SUBSYSTEM MODULE

The following two layouts illustrate a subsystem module and habitat module capable of supporting up to 11 men for 90 days. The subsystem module has a 3.8 m dia to the inside frames and is 15.75 m long. Five branch openings in the length of the cylinder provide passage and attachment points to other modules. One end of the module attaches to the external tank while the other end contains an international docking ring. The cylinder has a floor 0.725 m below center line and a 2 m ceiling. A center aisle of 1.3 m provides a large conference/meeting area for the 11-man crew and a generous passage way to the various attached modules. A sick bay with two beds and medical facilities is located in this module near the docking port for ready transfer of sick personnel to the orbiter. Two manned maneuvering units (MMU) and six extravehicular mobility units (EMU) are located adjacent to the airlock branch. Donning/doffing, suit drying and repair are performed in this area.

A control and display station, work bench/hobby shop, special purpose room, and film vault are located here. Floor-to-ceiling compartments and a full-length overhead compartment provide storage for personal and mission equipment.

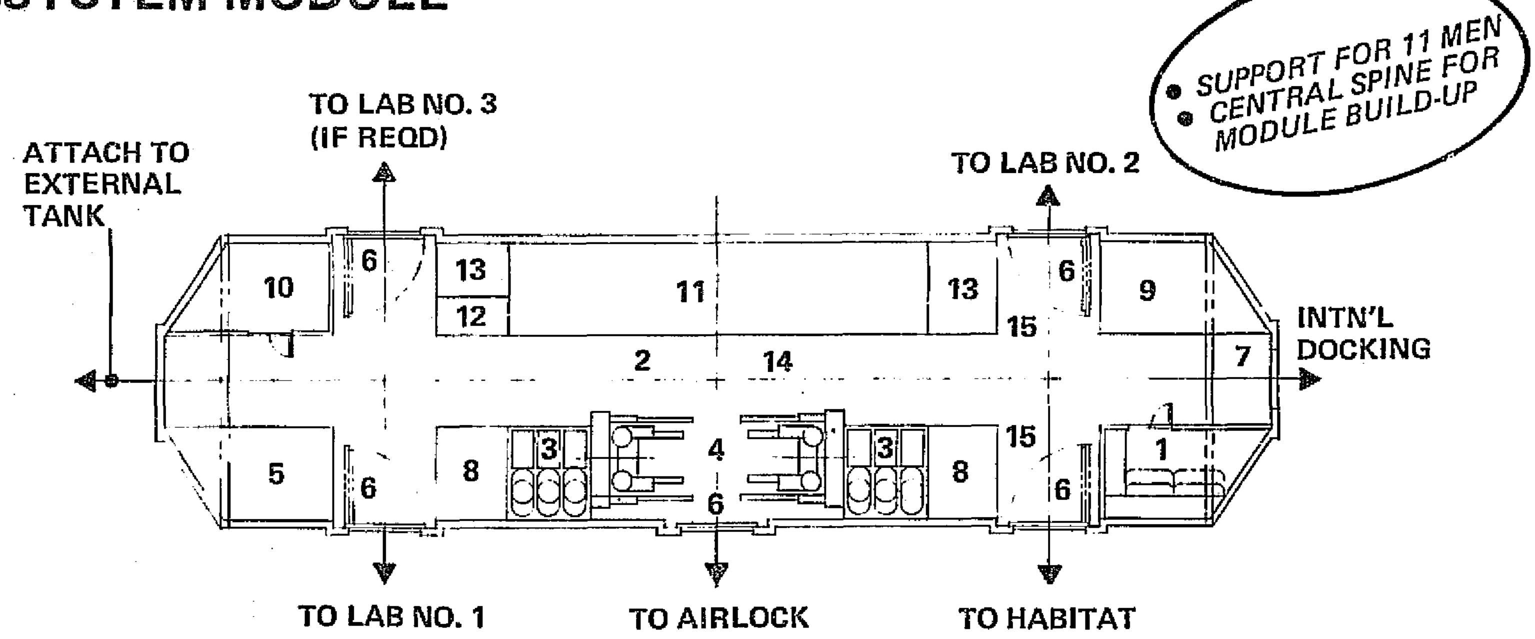
ECLS, electronics, navigation and guidance, EPS, etc. equipment are located in a floor to ceiling compartment 3 m long. Raising the floor in the central aisle provides access to approximately 25 m^3 of additional equipment installations.

Hatches at each branch provide a 1 m wide x 1.25 m high opening to attached module. These hatches can be left open for intermodule passage or closed to seal off adjacent module.

The international docking hatch provides an 0.82 m dia opening for transfer of crew and equipment to and from the orbiter.

G-326T

SUBSYSTEM MODULE



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CREW LIVING	CREW SUPPORT	MISSION SUPPORT
1. SICK BAY	3. EMU (6)	9. CONTROLS & DISPLAYS
2. AISLES/PASSAGEWAYS (1.3M)	4. MMU (2)	10. SPECIAL PURPOSE ROOM
	5. WORK BENCH/HOBBY SHOP	11. ELECTRONICS, ECS, ETC
	6. HATCH – 1.0x1.25M OPENING (4)	12. FILM VAULT
	7. HATCH – .82M OPENING (1)	13. STOWAGE
	8. STOWAGE	14. STOWAGE (CEILING)
		15. SUBSYSTEMS (BELOW FLOOR)

GRUMMAN

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HABITAT/SUBSYSTEM MODULE NO. 1

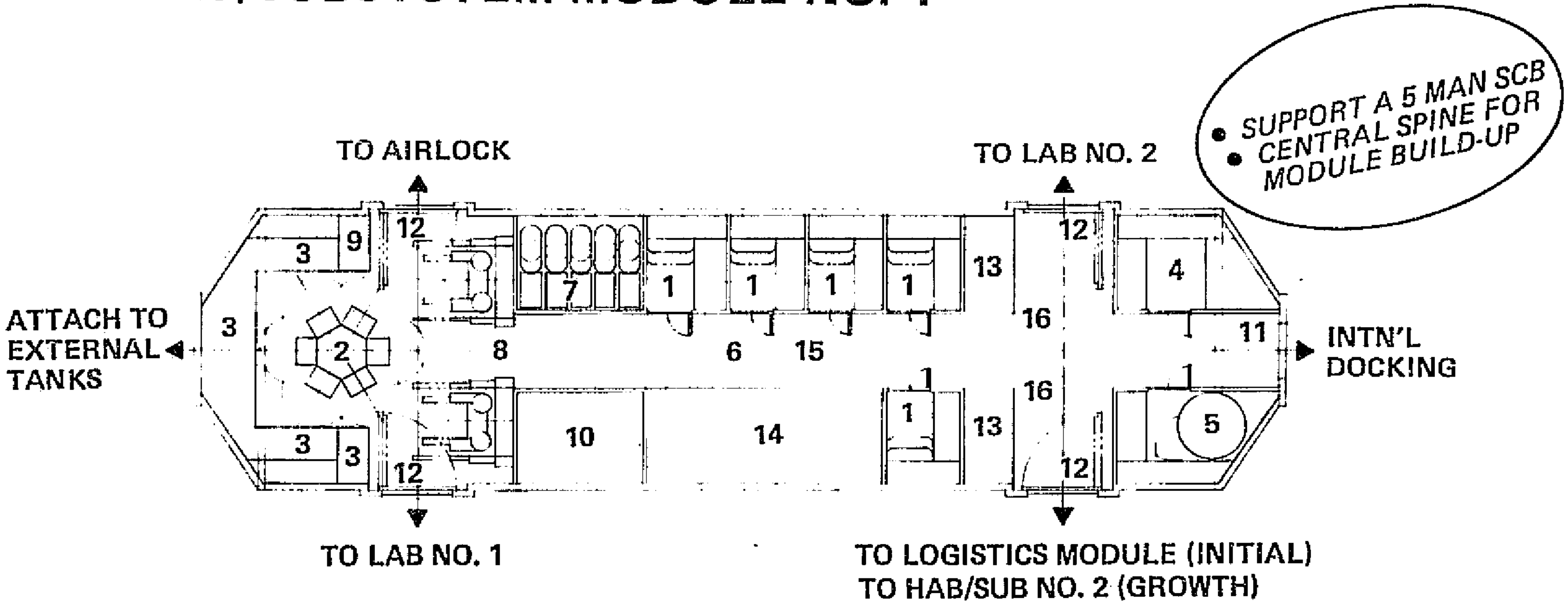
A second approach to packaging men and equipment is to integrate as many men with supporting equipment into one module. When required a second module can be added to increase the man power. The HAB/SUB module No. 1 shown can accommodate five men and supporting equipment. The overall dimensions and cross-sectional compartmentalization is the same as the habitat module described previously. A 1.1 m aisle with a 2 m ceiling runs the entire length. Four branch cylinders provide access and attachment points for additional modules. One end of the module is attached to the external tank while the other end contains an international docking ring. A waste management compartment and personal hygiene compartment, with shower, are located at this end. This location is near the HAB/SUB No. 2 module providing convenient access to these facilities. Five identical crew quarters are located in the central portion of the module, while the galley/wardroom is located at the far end. The dining table is configured to accommodate six men at one sitting, skylab equipment is used.

The two MMU's and five EMU's are located adjacent to the airlock branch module. All preparations concerned with EVA operation are performed in this general area. Two control and display stations located by the other branch cylinders will monitor the health of the entire SCB.

A full height floor to ceiling compartment, 1.7 m long, is provided for ECLS and electronic installations. Additional volume (25 m^3) is provided below the floor on either side of the central aisle. Stowage of flight support gear and equipment is provided in a floor to ceiling enclosure and a full length overhead compartment.

G-328

HABITAT/SUBSYSTEM MODULE NO. 1



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CREW LIVING	CREW SUPPORT	MISSION SUPPORT
1. CREW QUARTERS (5)	7. EMU (5)	13. CONTROLS & DISPLAYS
2. DINING AREA	8. MMU (2)	14. ELECTRONICS, ECS, ETC
3. GALLEY/FREEZER/CHILLER	9. REST & RECREATION EQUIP	15. STOWAGE CEILING
4. WASTE MANAGEMENT	10. STOWAGE	16. SUBSYSTEMS (BELOW FLOOR)
5. PERSONAL HYGIENE	11. HATCH – .82M OPENING	
6. AISLES/PASSAGEWAYS 1.1M	12. HATCH – 1.0 x 1.25M OPEN. (4)	

GRUMMAN

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HABITAT/SUBSYSTEM MODULE NO 2

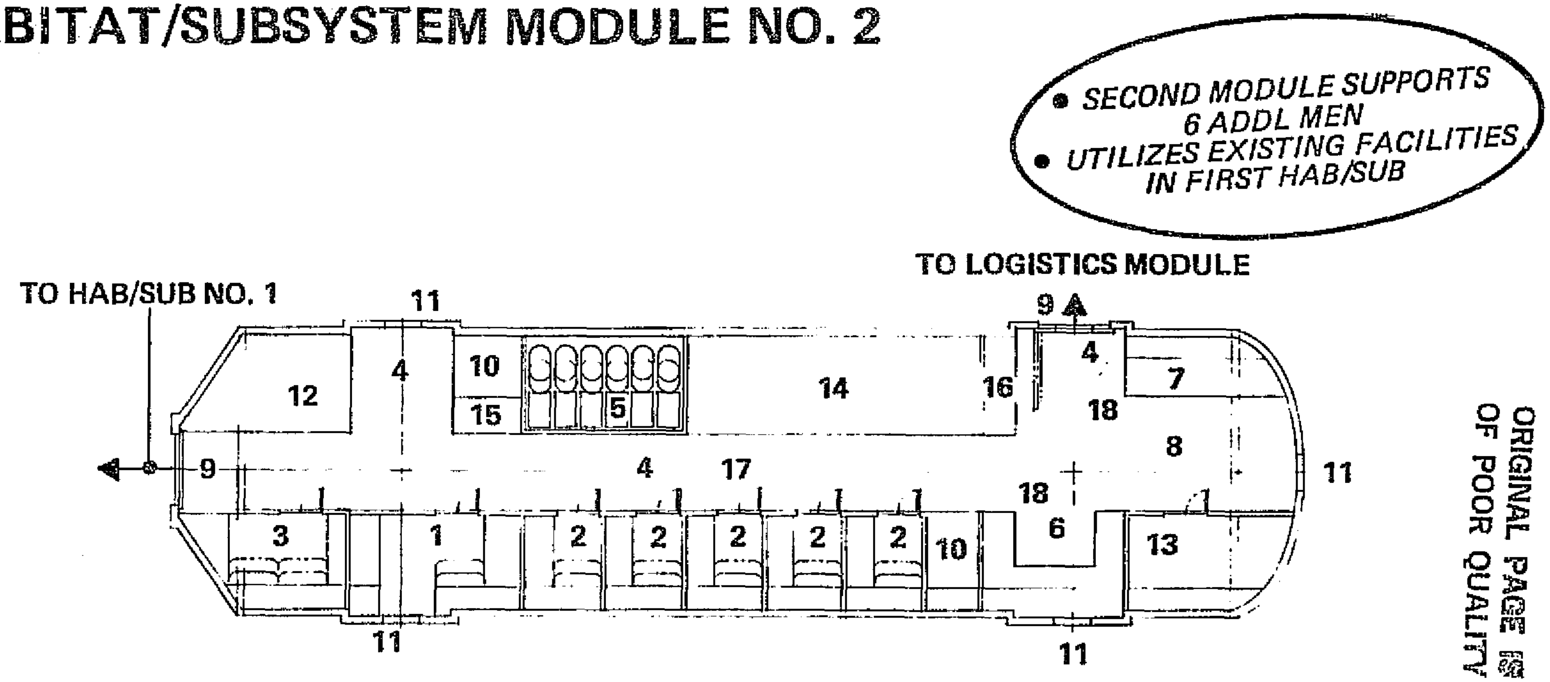
When the mission requires additional people a second habitat/subsystem module is added to the initial SCB. This module, when fastened to a branch cylinder of habitat/substem module No. 1, increases the habitatable capability from 5 to 11 crew members. The cross-sectional compartmentalization is identical to H/S No. 1 the added commanders quarters/office and five crew quarters will utilize the galley, W/M and personal hygiene facilities contained in H/S No. 1. A sick bay, special purpose room and work bench/hobby shop are located on either side of the aisle. An additional control and display area, stowage provisions for six additional EMU's, film vault and crew equipment are provided.

A floor to ceiling compartment, 2 m long, accommodates the ECLS and electronics installations. Additional volume for subsystem installations is provided below the floor on either side of the central aisle. In addition, a full length overhead compartment will provide added stowage volume.

The far end of the domed shaped cylinder is used to locate the rest and recreation equipment and exercise center. Four 50 cm dia windows provide visibility to the outside. The logistics module is attached to the branch cylinder at the far end of the module, in this arrangement large distances must be traversed when off loading resupplies.

G-329

HABITAT/SUBSYSTEM MODULE NO. 2



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CREW LIVING	CREW SUPPORT	MISSION SUPPORT
1. CMDRS QTRS/OFFICE	5. EMU (6)	12. CONTROLS & DISPLAYS
2. CREW QUARTERS (5)	6. WORK BENCH/HOBBY SHOP	13. SPECIAL PURPOSE ROOM
3. SICK BAY	7. REST & RECREATION EQUIP	14. ELECTRONICS/ECS, ETC.
4. AISLES/PASSAGEWAYS (1.1M)	8. EXERCISE CENTER	15. FILM VAULT
	9. HATCH – 1.0 x 1.25M OPEN.(2)	16. STOWAGE
	10. STOWAGE	17. STOWAGE (CEILING)
	11. 50 CM WINDOW (4)	18. SUBSYSTEMS (BELOW FLOOR)

GRUMMAN

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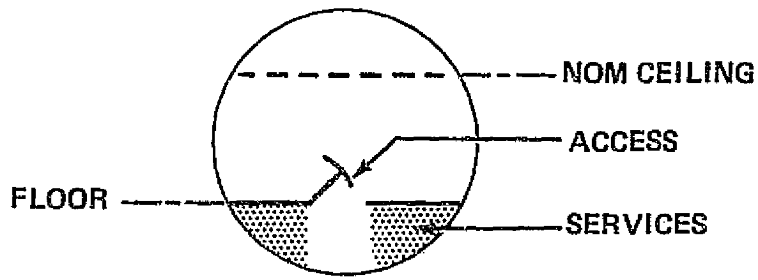
HAB – SUB – LAB MODULE SUMMARY

- ONE FLOOR LEVEL
- PRELIM STANDARD MODULE
  - 15.7 M LONG
  - 4.0 M DIA WITH FIVE 1.6 M DIA BRANCHES
  - TWO TYPES OF END DOMES
- BETWEEN ONE & FOUR OF THESE MODULES ON EACH SCB
- THREE TYPES OF INGRESS/EGRESS
  - INTERNATIONAL DOCKING – .8 M DIA
  - MODULE EXCHANGE – 1.0 M X 1.25 M
  - EVA AIRLOCK – 1.0 M X 1.25 M
- COMMON INTERIOR CROSS SECTION



- 4 – 6 ARRANGEMENT VARIATIONS ABOVE FLOOR DEPENDING ON PROGRAM OPTION
- SPACELAB PRESS VESSEL USED FOR BRANCH MODULES

G-413

GRUMMAN

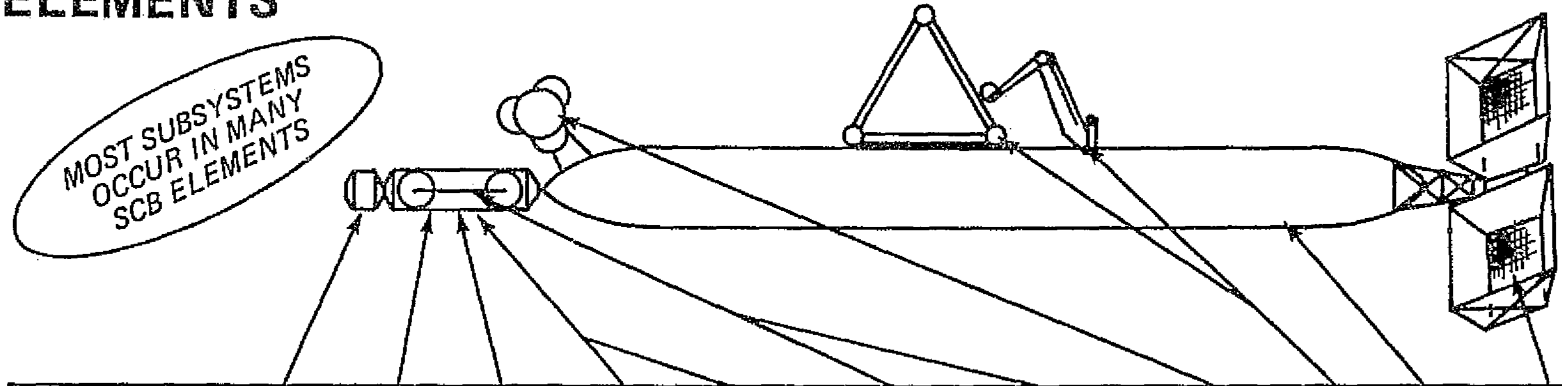
SPREAD OF SUBSYSTEM MASSES (KG's) ACROSS SCB ELEMENTS

The chart on the opposite page shows the spread of the subsystem dry weights across typical SCB elements. The Space Construction Base show is Option 2B with the orbital depot in place. As can be seen, all subsystems except RCS are utilized in several of the SCB elements.

The long modules (habitat, subsystem and laboratories) are sized to fill the STS payload bay when the STS docking module is installed. Unless they are literally stuffed with materials and/or mission equipment, they are STS payload volume limited for most 28½ deg LEO flights.

G332T

SPREAD OF SUBSYS MASSES (KG'S) ACROSS TYPICAL SCB ELEMENTS



ELEMENTS / SUBSYST	LOGIS	HABIT	SUBSYS	LAB NO. 1	LAB NO. 2	AIRLOCK	3 SP MAN BRANCH'S	ORB DEP	CONST SYST	EXT TANKS	SOLAR ARRAY
STRUCTURE	3,685	6,313	6,508	6,543	6,596	1,932	6,016	2,720	15,380	5,262	680
IND ENVIR PROT	125	431	431	431	431	125	375	3,000			
PROPULSION - RCS										340	
PRIME POWER - EPS	105	1,125	2,895	1,125	1,125	105	315	280	400		1,650
AVIONICS	8	88	2,050	88	88	8	24		101		
ENVIRON CONTROL	335	2,821	1,874	410	410	65	195				
PERSONNEL PROV	155	1,912	813	440	440	95	285		222		
SPARES		700	230								
CONTINGENCY	1,103	3,348	3,700	2,259	2,273	583	1,803	1,500	4,026	1,401	583
TOTAL - DRY	5,516	16,738	18,501	11,296	11,363	2,913	9,013	7,500	20,129	7,003	2,913

NOTE: WEIGHTS OF EXT TANKS, SPDA & OTV-PC'S ARE NOT INCLUDED

SUBSYSTEM DEVELOPMENT DATA COMPONENT MASSES STRUCTURE (MODULES)

The structural weight has been determined for each module used in the various program options. "Long" modules (15.75M Long) are used for subsystems, habitation, and laboratories as well as the combined subsystem/habitation and the GEO's outpost modules. The short modules are Space-lab equipment and are used for space manufacturing branches, airlocks and logistic modules.

The long module cylinder, floor and ceiling are assumed to be the same for all long cylinders and the weight, therefore, appears only once in the non-replicated weight column.

The domed end is unique to the habitation module and appears as the cost input weight. The hard mound end is similar to Space-lab and is used for all other module ends; a percent of the shelf value of 30% has been assigned because of the similarity to the Space-lab structure.

The unit weight of a port and closure is 105 kg and is a new development; it is used a varying number of times in the long modules.

The docking tunnel is a new development item that provides an extended "neck" on the logistics module for external placement of high pressure tankage.

Equipment mounting is different in each module. It is reasoned, however, that not all equipment mounting structure will be new. A conservative estimate of 500 kg has been assumed as non-replicated weight.

SUBSYSTEM DEVELOPMENT DATA

COMPONENT MASSES

STRUCTURES (MODULES)	COST INPUT		WEIGHT, KG						
	NON REP WT, KG	% OFF SHELF	SUBSYS	HABITAT	SS/HAB	OUTPOST	LAB	SPACELAB	OTHER
• CYLINDER									
– 14.6 M LONG	3,300	0	3,300	3,300	3,300	3,300	3,300		
– 2.6 M LONG	588	80						588	
• ENDS									
– DOMED	456	0		456					
– HARD MOUNT	602	30	1,204	602	1,204	1,204	1,204	1,204	
• FLOOR									
– 14.6 M LONG	420	0	420	420	420	420	420		
– 2.6 M LONG	75	80						75	
• CEILING									
– 14.6 M LONG	210	0	210	210	210	210	210		
- 2.6 M LONG	38	80						38	
• PORTS	105	0	630	630	630	420	>630		
• DOCKING TUNNEL	280	0						>280	
• EQUIP. MOUNTING	500	0	744	695	720	687	>1,012	>1,500	
SUBTOTAL W/O CONT	5,873	11	6,508	6,313	6,484	6,241	>6,776	>3,685	
25% CONTINGENCY			1,627	1,578	1,621	1,560	1,694	921	
TOTAL – DRY			8,135	7,891	8,105	7,801	>8,470	>4,606	

GRUMMAN

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SUBSYSTEM DEVELOPMENT DATA COMPONENT MASSES STRUCTURES (OTHER)

Other structures encompass all other SCB hardware (except mission equipment) that is not physically located on or in the modules. These include the external tank modifications, construction aids, orbital depot and miscellaneous items.

With the exception of the international docking system all items are assumed to be new development.

Non replicated weights include only one of items that are used more than once. For example, the cherry picker arms elbows, wrists and bubble all occur twice but only one of each is included in the non-replicated weight. The cost input weights are determined in a similar manner for all other structures.

G364T

SUBSYSTEM DEVELOPMENT DATA
COMPONENT MASSES

STRUCTURES (OTHER)	COST INPUT		WEIGHT, KG						
	NON REP WT, KG	% OFF SHELF	SUBSYS	HABITAT	SS/HAB	OUTPOST	LAB	SPACELAB	OTHER
• EXT TANK MODS	1,251	0							2,681
• CHERRY PICKER	2,600	0							4,186
• AUTO FAB MODULE	3,356	0							3,356
• AUTO FAB MOUNTING	170	0							335
• CONSTRUCTION GUIDES	160	0							368
• DOCKING RING	422	80							422
• PSP TURNTABLE	380	0							680
• 150 KW S/A TOWER	170	0							680
• SEPS S/A TOWER	29	0							116
• ORBITAL DEPOT									
– TURNTABLE	450	0							900
– TORPEDO NET	500	0							1,500
– STRUCTURE	400	0							1,200
• SOLAR STORM SHELTER	100	0							8,662
SUBTOTAL W/O CONT	9,988	3							25,036
25% CONTINGENCY									6,259
TOTAL – DRY									31,295

GRUMMAN

G-364

SUBSYSTEM DEVELOPMENT DATA COMPONENT MASSES INDUCED ENVIRONMENTAL PROTECTION

The Induced Environmental Protection consists of micrometerorite shielding, insulation and attachments. Although similar protection has been used in the past, it is considered to be new development in this report, hence, zero % off the shelf. The design concept is to provide common "building block" components that are assembled to form the complete module protection.

G363T

SUBSYSTEM DEVELOPMENT DATA
COMPONENT MASSES

IND ENVIRON PROTECTION	COST INPUT		WEIGHT, KG						
	NON REP WT, KG	% OFF SHELF	SUBSYS	HABITAT	SS/HAB	OUTPOST	LAB	SPACELAB	OTHER
• MICROMETEORITE SHIELDING	34	0	103	103	103	103	103	30	
• INSULATION	48	0	144	144	144	144	144	42	
• ATTACHMENTS	33	0	98	98	98	98	98	28	
SUBTOTAL W/O CONT	115	0	345	345	345	345	345	100	
25% CONTINGENCY			86	86	86	86	86	25	
TOTAL – DRY			431	431	431	431	431	125	

GRUMMAN

G-363

SUBSYSTEM DEVELOPMENT DATA COMPONENT MASSES PROPULSION (RCS)

Reaction Control System weights are assembled using a high percentage of off the shelf components. The thrusters, tankage and pressurization system are substantially developed and are therefore, assigned an 80% off-the-shelf value. The remaining components are new development items.

Since there are four RCS modules, the non replicated weight is one quarter of the total system dry weight (without contingency).

The RCS system modules are generally not attached to modules and the weight, therefore, is recorded in the "other" column.

G362T

SUBSYSTEM DEVELOPMENT DATA
COMPONENT MASSES

PROPULSION (RCS)	COST INPUT		WEIGHT, KG						
	NON REP WT, KG	% OFF SHELF	SUBSYS	HABITAT	SS/HAB	OUTPOST	LAB	SPACELAB	OTHER
• THRUSTERS	15	80							60
• PRESSURIZATION SYS	29	80							116
• PROPELLANT UTIL									
– TANKAGE	16	80							64
· PLUMBING	5	0							20
• SUPPORTS	20	0							80
SUBTOTAL W/O CONT	85	56							340
25% CONTINGENCY									80
TOTAL – DRY									425

GRUMMAN

G-362

SUBSYSTEM DEVELOPMENT DATA COMPONENT MASSES PRIME POWER (EPS)

Electrical Power Systems weights represent the subsystem requirements assuming the electrical power and energy storage are provided by 150 kw SPDA or SEPS solar power systems.

The largest weight in the subsystem is the distribution. All wires are aluminum and all connectors are assumed to be off the shelf. Although the total weight is considerable the non replicated weight for unique cable assemblies is estimated to be 20 kg. Percent off the shelf is high because all connectors are already developed.

The battery/array processor is new equipment. Each processor module is 12.5 kg and a total of eight are required.

Remaining equipments have been similarly assessed for non replicated weight and percent off the shelf.

G361T

SUBSYSTEM DEVELOPMENT DATA
COMPONENT MASSES

PRIME POWER (EPS)	COST INPUT		WEIGHT, KG						
	NON REP WT, KG	% OFF SHELF	SUBSYS	HABITAT	SS/HAB	OUTPOST	LAB	SPACELAB	OTHER
• BATTERY/ARRAY PROC	13	0	100		100	100			
• CONDITIONING EQUIP									
– PRIMARY	200	30	200						
– LOCAL	–	–		225	225	225	>225	25	
• DISTRIBUTION-FEEDERS									
– PRIMARY	20	70	1,985		900	900			
– LOCAL	–	–		750			>750	65	
• DISTR CONTROL PANELS									
– PRIMARY	50	50	610		300	300			
– LOCAL	–	–		150			>150	15	
• SPARES	–	–		200	100	100			
SUBTOTAL W/O CONT	283	35	2,895	1,325	1,625	1,625	>1,125	105	
25% CONTINGENCY			724	331	406	406	281	26	
TOTAL – DRY			3,619	1,656	2,031	2,031	>1,406	131	

GRUMMAN

SUBSYSTEM DEVELOPMENT DATA COMPONENT MASSES AVIONICS

The avionics used in the SCB's have a high percentage off the shelf. Most components have been developed for other space applications and are used with only minor modifications. The circuitry is new development for the space construction bases.

The non-replicated weight has been determined based upon commonality as has been explained in previous pages.

G368T

SUBSYSTEM DEVELOPMENT DATA

COMPONENT MASSES

AVIONICS	COST INPUT		WEIGHT, KG						
	NON REP WT, KG	% OFF SHELF	SUBSYS	HABITAT	SS/HAB	OUTPOST	LAB	SPACELAB	OTHER
• STABLIZATION & CONT	(215)	(80)							
– SENSORS	5	80	15		15	15			
- COMPUTER	20	80	20		20	20			
– CMGs	190	80	380		380	190			
• COMM & TRACKING	(382)	(56)							
– UNITS	150	60	150		150	150			
– CURCUITRY	78	0	78		78	78			
– ANTENNAS	154	80	154		154	154			
• DISPLAYS & CONTROLS	(468)	(48)							
– DISPLAY UNITS	402	50	402	60	200	150	60		
– RCS JET DRIVERS	27	80	54		54	54			
– CIRCUITRY	39	0	39	5	21	16	5		
• INSTRUMENTATION	(179)	(74)							
– SENSORS	6	80	30	20	30	30	20	5	
– SIG COND/RCDRS	159	80	159		159	159			
– CIRCUITRY	14	0	14	3	14	14	3	3	
• DATA PROCESSING	(555)	(55)							
– GEN PURP CMPTR	283	80	283		283	283			
– SOFTWARE	272	30	272		150	100			
• SPARES	–	–		100	75	50			
SUBTOTAL W/O CONT	1,799	58	2,050	188	1,783	1,463	88	8	
25% CONTINGENCY			513	47	446	366	22	2	
TOTAL – DRY			2,563	235	2,229	1,829	110	10	

GRUMMAN

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SUBSYSTEM DEVELOPMENT DATA COMPONENT MASSES ENVIRONMENTAL CONTROL

A considerable number of the ECS components have been developed for other space applications and are used with only minor modifications. The $CO_2 - O_2$ units, the urine waste management, the freon radiator, and the ducting and plumbing are new development items for the Space Construction Bases.

The non-replicated wieght has been determined based upon common usage as explained in previous pages.

G367T

SUBSYSTEM DEVELOPMENT DATA

COMPONENT MASSES

ENVIRON CONTROL	COST INPUT		WEIGHT, KG						
	NON REP WT, KG	% OFF SHELF	SUBSYS	HABITAT	SS/HAB	OUTPOST	LAB	SPACELAB	OTHER
• AIR REVITALIZATION									
– CO_2-O_2 UNITS	448	0	1,052		526	526			
– HUMIDITY CONT	174	30	205		103	103			
– ATMOS COMP. CONT	15	60	17		17	17			
– TRACE CONTAM	110	40	122		61	61			
– N_2 BOTTLES	17	80	68		34	34		>270	
• WATER MGMT									
– PROCESSING	275	30		335	335	335			
– TANKS	78	80		156	78	78			
• WASTE MGMT									
– SOLIDS	225	80		450	225				
– URINE	195	0		530	265				
• THERMAL CONTROL									
– WATER LOOP	154	20	210	210	210	100	210	35	
– FREON HX	70	80	70	70	70	70	70		
– FREON PUMPS	60	80		120	120	120			
– FREON RADIATOR	51	0		810	410	200			
• DUCTING & PLUMBING	30	0	130	130	130	130	130	30	
• SPARES	–	–	230	400	430	150			
SUBTOTAL W/O CONT	1,902	30	2,104	3,221	2,984	1,924	410	>335	
25% CONTINGENCY			526	805	746	481	103	84	
TOTAL – DRY			2,630	4,026	3,730	2,405	513	>419	

GRUMMAN

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SUBSYSTEM DEVELOPMENT DATA COMPONENT MASSES PERSONNEL PROVISIONS

Personnel provisions weights have been estimated for each module. Partitions, stowage, supports, lighting and interior finishes are assumed to be new development items. Lockers and furnishing equipment are mostly new but do utilize some existing hardware.

Remaining items of crew support and mission equipment are fundamentally identical to existing space flight developed components and are therefore, given a high percentage "off the shelf".

Non replicated weight had been determined as described in preceeding pages.

G366T

SUBSYSTEM DEVELOPMENT DATA

COMPONENT MASSES

PERSONNEL PROVISIONS	COST INPUT		WEIGHT, KG						
	NON REP WT, KG	% OFF SHELF	SUBSYS	HABITAT	SS/HAB	OUTPOST	LAB	SPACELAB	OTHER
• FURNISHINGS									
– PARTITIONS	102	0	102	441	262	102	60		
– LOCKERS	20	30	20	110	50	50			
EQUIPMENT	50	25	85	67	45	45	50		
– STOWAGE	50	0	52	52	52	52	50	>100	
– SUPPORTS	35	0	70	70	70	70	20	> 15	
• CREW SUPPORT									
– FOOD MGMT	135	75		331	186				
– HOUSEKEEPING	35	70	15	93	67	15	15		
– WASTE MGMT	28	80		28	28	28			
– PERS. HYGIENE	55	80		75	40	25			
– RESTRAINTS	20	0	50	50	50	50	50	20	
– LIGHTING	15	0	75	55	75	75	55	20	
– PERS. EQUIP.	126	80	229	245	269	50	50		
– FINISHES	30	0	90	90	90	90	90	30	
• MISSION EQUIP.									
– FILM VAULTS	100	80		200	200				
– TV CAMERA	5	80	5	5	5				
– CAMERAS	20	80	20						
SUBTOTAL W/O CONT	826	38	813	1,912	1,489	652	440	>155	
25% CONTINGENCY			203	478	372	163	110	39	
TOTAL – DRY			1,016	2,390	1,861	815	550	>194	

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SUBSYSTEM DEVELOPMENT DATA – SUMMARY

The non-replicated weights and percent off-the-shelf values shown on the facing chart are the summations of the individual subsystem charts shown on the preceeding seven pages. This summation shows that only 21,572 kg of all Space Construction Base dry weights are new development items. Further, 14% of that weight is "off-the-shelf" hardware.

As has been seen on the previous pages subsystem component weights are tabulated for each SCB module. All duplicated common weight appearing in more than one SCB module is removed from the non-replicated weight column. This non-replicated weight is then summated for each subsystem and the weighted average percent off-the-shelf determined. That data is brought forward to the summary chart opposite.

G360T

SUBSYSTEM DEVELOPMENT DATA SUMMARY
NON REPLICATED WEIGHT, % OFF SHELF & DDT & E COST %

ONLY 21,572 KG OF ALL SCB DRY WEIGHTS ARE NEW DEVELOPMENT

SUBSYSTEM	NON REPLICATED WT, KG	% OFFSHELF	% DDT&E COST
• STRUCTURE (MODULES)	6,574	11	44.9
• STRUCTURES (OTHER)	9,988	3	13.6
• INDUCED ENVIRONMENTAL PROTECT	115	0	5.5
• PROPULSION (RCS)	85	56	0.2
• PRIME POWER (EPS)	283	35	7.0
• AVIONICS			
– STAB. & CONTROL	215	80	0.5
– COMM & TRACKING	382	56	2.8
– DISPLAYS & CONTROLS	468	48	12.7
– INSTRUMENTATION	179	74	
– DATA PROCESSING	555	55	
• ENVIRONMENTAL CONTROL	1,902	30	7.0
• PERSONNEL PROVISIONS	826	38	5.8
TOTAL	21,572	14	100

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POTENTIAL OBSTACLES TO ACROSS THE BOARD SUBSYSTEM COMMONALITY

The chart on the opposite page shows graphically the potential changes to pertinent subsystem requirements and hardware for the various program options.

Little or no changes are required for the operational low earth orbit — 28½ deg Space Construction Bases as the options change.

The Option 3, LEO-high inclination Solar Territorial Observatory has different requirements that may warrant subsystem changes. All changes are directed towards removing weight and making it easier to obtain this orbit. Power requirements are lower and a SEPS array may be substituted for the 150 kw SPDA. Flight control requirements are less and could result in smaller flight control equipment. Since there is no construction in this option, auxilliary aids and external tanks are not required.

The geostationary orbit options involve large transportation costs that make subsystem changes that reduce weight attractive. As in Option 3 smaller power and flight control requirements could result in lower weights. Communications could probably be reduced also. For the manned, Option 2A, however, we must add substantial weight to provide protection against solar storms. The large transportation costs prohibit using the external tanks in geostationary orbit.

G396T

POTENTIAL OBSTACLES TO ACROSS-THE-BOARD SUBSYSTEMS COMMONALITY

SOME SUBSYSTEMS WANT TO CHANGE IN HI-INCL & GEOS ORBITS

	LEO						GEOS	
	28½°					HI-INCL	0°	
PROG OPTION	INITIAL ALL	ADV 1A/B	2A	2B	3	3	2A	2B
CREW SIZE	5	10	8	11	10	3	3	0
PERS PROVs	MODULAR ~ VARIES WITH CREW							
ECLS	MODULAR ~ VARIES WITH CREW							
EPS • REQMT	17	65	60	65	65	25	33	18
EPS • SOURCE • STORAGE	150 KW SPDA MUST COVER OCCULSION					SEPS ARRAY LESS OCCULUSION		
FLT CONTROL RCS	LARGE ~ HI GRAV GRAD COMMON RCS ~ EXT TK MTD					SMALLER ~ MODULE MTD		
AVIONICS – COMM	LEO NETWORK						GEOS	
ENVMT PROTECT • BASIC SS	LOW RAD (SAA)						HI-RAD	
ENVMT PROTECT • AUX AIDS	LOW RAD (SAA)						HI-RAD	
STRUCT • EXT TK	LOW COST CONSTR SPINE							
STRUCT • STND MODULES	COMMON MODULES							

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SUBSYSTEM SUMMARY

- DISPERSED WIDELY ACROSS THE CONFIG
- DEVELOPMENT COST HELD DOWN BY MODULARITY (REPLICATION) & USE OF OFF-THE-SHELF ITEMS
- POTENTIAL SUBSYSTEM CHANGES AT HI-INCL & GEOS
  - SMALLER/LIGHTER POWER SUPPLY & STORAGE
  - FLT CONTROL – SMALLER/LIGHTER STATION – CHANGING ENVIRMT & REQMTS
  - COMM-SIMPLER NETWORK/LIGHTER
  - RADIATION PROTECTION – MORE SEVERE ENVRMT

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ECLS SUBSYSTEM REQUIREMENTS

This chart outlines the major functional requirements of the ECLS system. In general, these requirements may be grouped into two broad functional areas; Life Support and Thermal Control. The Life Support section includes all areas necessary to support the crew (except food management) while the Thermal Control section provides active cooling for all modules and subsystems.

G354T

ECLS SUBSYSTEM REQUIREMENTS

LIFE SUPPORT

- REMOVAL OF METABOLIC CO_2 FROM ATMOSPHERE
- RECLAMATION OF O_2 FROM CO_2
- GENERATION OF O_2 & CONTROL OF ATMOS PRESS. & COMPOSITION
- REMOVAL OF TRACE CONTAMINANTS
- COLLECTION & RECLAMATION OF POTABLE WATER FROM URINE
- STERILE STORAGE & MONITORING OF QTY & QUALITY OF POTABLE WATER
- COLLECTION, RECLAMATION & STORAGE OF WASH WATER

THERMAL CONTROL

- PROVIDE ACTIVE THERMAL CONTROL FOR
  - CABIN ATMOSPHERE
  - AIR COOLED ELECTRONICS
  - COLD PLATE COOLED ELECTRONICS
  - EXPERIMENTS/PROCESSING EQUIPMENT/MFG ETC.
- PROVIDE FOR WASTE HEAT REJECTION BY USE OF ACTIVE SYSTEMS (E.G. SPACE RADIATOR, BOILING ETC.)

OTHER

- PROVIDE EVA/PLSS RECHARGE STATIONS
- PROVIDE EMERGENCY/BACKUP ECLS SYSTEMS

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TYPICAL COOLING LOAD, KW

This chart shows the typical heat loads placed on the ECLS subsystem and indicates the primary mode of removal (i.e. air or liquid). The load in the external column are those dissipated in the power source side (SPDA) and are not removed by the ECLS.

G-422T

TYPICAL COOLING LOAD (KW) PRGRM OPT 1A/B-LEO/28½°
TIME ~ LATE 80's

CONSUMER/HEAT SOURCE	AV PWR KW	COOLING CATEGORY RACK/AIR	COLD PLATE/RAIL	EXTERNAL
CREW	1.6	1.6		
PWR • LOAD SIDE DIST LOSS	7.0	7.0		
• LOAD SIDE COND LOSS	9.7		9.7	
• SOURCE SIDE DIST LOSS	3.8			3.8
• SOURCE SIDE COND LOSS	4.9			4.9
• STORAGE LOSS	26.8 (52.2)			26.8 (35.5)
ECLS/WASTE MGMT	11.5	6.2	5.3	
COMM/INSTR/DATA HANDLING	0.7	0.7		
CONT & DISPLAY	0.4	0.4		
ONBOARD C/O	0.8	0.6		0.2
GUID & CONT/PROPULSION	1.5	1.0		0.5
DOCK/AIRLK/EVA SUIT SVCE	0.5	0.5		
ILLUMINATION	3.0	1.0		2.0
FOOD & HYGIENE	3.1	3.1		
RECREATION	0.5 (10.5)	0.5 (7.8)		(2.7)
SPACE MFG • BIOLOGICAL	5.3	5.3		
• MAGNETS	4.6	0.4	4.2	
• S1 RIBBON	2.7	1.3	1.4	
• MFG DEVEL	5.0 (17.6)	2.5 (9.5)	2.5 (8.1)	2.5 (8.1)
ENG TEST LAB	13.7	11.7	2.0	
CONSTR • AUTO FAB (3)	3.8			3.8
• CRANE	2.0			2.0
• Q/C & C/O LAB	1.0 (6.8)	0.5		0.5 (6.3)
ORB DEPOT	1.0	1.0		
TOTALS	114.9	45.3	25.1	44.5

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ECLS STRAWMAN EQUIPMENT FUNCTION & BASELINE CONCEPT

The following two charts are a breakdown of the ECLS subsystem showing the concept baselined for each function and the technology base for each concept. In all areas, the technology has been developed or is presently being developed. We rely heavily on the Regenerative Life Support Evaluation (RLSE) work presently under way to provide the technology for the regenerable oxygen portions of the ARS and the water reclamation systems. A preliminary weight breakdown of the ECLS Subsystem is presented in the mass properties section of this report.

G355T

ECLS STRAWMAN EQUIP FUNCTION & BASELINE CONCEPT

LIFE SUPPORT (SHEET 1 of 2)

SYSTEM USES EXISTING OR IN-WORK TECHNOLOGY

SECTION & FUNCTION	CONCEPT	TECHNOLOGY BASE
• ATMOSPHERE REVITALIZATION		
– CO_2 REMOVAL	ELECTROCHEM DEPOLARIZED CONCENTRATOR	RLSE
– CO_2 REDUCTION	SABATIER BEACTOR	RLSE
– O_2 GENERATION	SOLID POLYMER WATER ELECTROYSIS	RLSE
– HUMIDITY CONTROL	CONDENSING LIQ/AIR HEAT EXCHRGR	SHUTTLE/SPACELAB
– ATMOS COMP & PRESS. CONTROL	N_2/O_2 TWO-GAS CONTROL SYSTEM	SHUTTLE/SPACELAB
– GAS STORAGE (N_2 TANK)	HIGH PRESSURE TANKS	SHUTTLE/SPACELAB
– TRACE CONTAMINANT REMOVAL	CATALYTIC CONV, ABSORB., FILTRATION	RLSE
• WATER MGMT		
– WATER TANK	ACCUMULATOR	SHUTTLE
– WASH WATER RECLAMATION & PROCESSING, STERILIZATION	HYPERFIL (REVERSE OSMOSIS), IODINE	RLSE
– QUALITY MONITORING	PH MONITORING, TOC, ETC.	RLSE
• WASTE MGMT		
– SOLID WASTE COLLECT & PROC'G	VACUUM DRY (SHUTTLE TYPE)	SHUTTLE
– URINE PROC'G & RECLAMATION	VAPOR COMPRESSION DISTILLATION	RLSE

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ECLS STRAWMAN EQUIP FUNCTION & BASELINE CONCEPT
THERMAL CONTROL (SHEET 2 OF 2)

SYSTEM USES EXISTING OR IN-WORK TECHNOLOGY

SECTION & FUNCTION	CONCEPT	TECHNOLOGY BASE
• HEAT TRANSPORT SECTION	WATER LOOP & PUMPS, ACCUM, ETC	SHUTTLE/SPACELAB/LM
– CABIN/MODULE COOLING	LIQ/AIR HEAT EXCHGR/FAN	SHUTTLE/SPACELAB/LM
– AVIONICS COOLING		
o AIR COOLING	AIR/LIQ HX/FAN CLOSED LOOP	SHUTTLE/SPACELAB
o COLD PLATE	LIQ COOLED COLD PLATES/RAILS	SHUTTLE/SPACELAB/LM
• HEAT REJECTION SECTION	PUMPED FREON LOOP SERVICING HEAT EXCHGRS IN EACH MODULE	SHUTTLE/SPACELAB
– RADIATOR		

GRUMMAN

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STRAWMAN ECLS SUBSYSTEM DESCRIPTION

This chart presents a brief description of the ECLS for the two major SCB options presently under study and illustrates how vehicle design influences subsystem concepts. In the basic option with separate Habitat and Subsystem modules, we have chosen to size the Life Support section to handle the eventual full crew compliment. This choice was made because the majority of the ECLS processing equipment will be located in the Subsystem Module and by installing a full size system initially, the major cost and complexity on an in-orbit retrofit is avoided. In addition, changes in program or mission objectives involving crew size can be implemented with little or no impact on the operational SCB.

In the second major option, the combined Hab/SS concept, we equip each module with a complete system sized for six men because the only way crew size can be changed is for a second Hab/SS module to be added to the SCB complex. Thus there is no retrofit required to the operational complex and each Hab/SS module is fully independent.

G352T

STRAWMAN ECLS SUBSYSTEM DESCRIPTION

SCB OPTION
DRIVES SUBSYSTEM
SIZING POINT

SCB OPTION	
HABITAT PLUS SUBSYSTEM	**COMBINED HABITAT/SUBSYSTEM**
• LIFE SUPPORT – SIZED FOR 12 MEN – MAJOR PROCESSING EQUIP IN SUBSYSTEM MODULE – CREW USE EQUIP (E.G. WASTE MGMT) IN HABITAT MODULE – CONSUMABLES IN LOGISTICS MODULE • THERMAL CONTROL – CENTRAL HEAT REJECTION LOOP (FREON) & RADIATOR SERVICING ALL MODULES – SEPARATE HEAT TRANSPORT LOOP (WATER) IN EACH MODULE TAILORED TO SPECIFIC LOADS	• LIFE SUPPORT – EACH HAB/SUBSYS MODULE HAS COMPLETE LIFE SUPPORT SECTION SIZED FOR 6 MEN – CONSUMABLES IN LOGISTICS MODULE • THERMAL CONTROL – SEPARATE HEAT REJECTION LOOP & RADIATOR FOR EACH HAB/SUBSYS MODULE SERVICING BASIC MODULE & ATTACHED SUBMODULES – SEPARATE HEAT TRANSPORT LOOP IN EACH MODULE TAILORED TO SPECIFIC LOADS

GRUMMAN

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ATMOSPHERE REVITALIZATION SCHEMATIC

This schematic highlights the major processing equipment in the ARS.

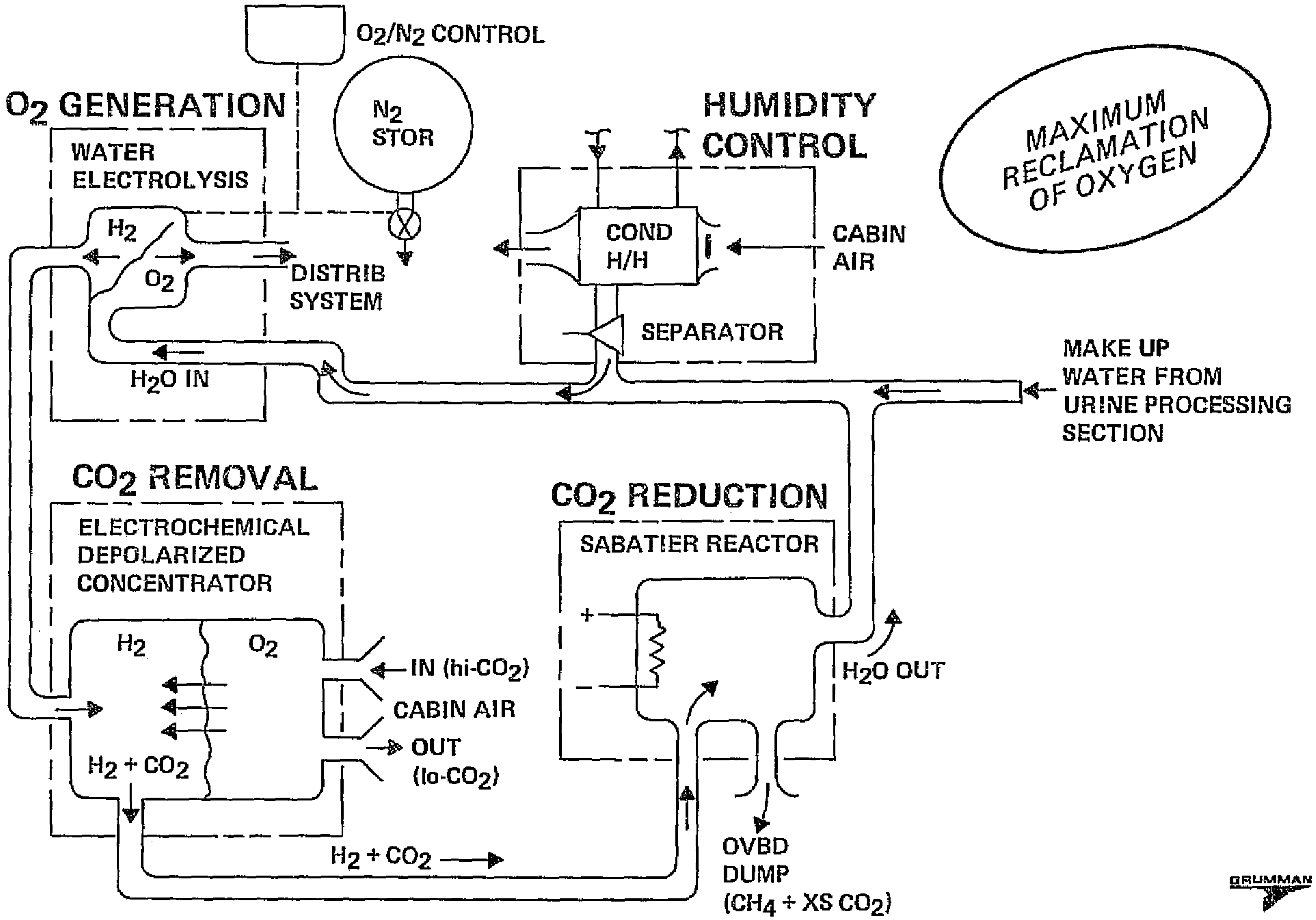
The main function of the ARS is to recover breathable oxygen from metabolic carbon dioxide in addition to removing excess humidity and trace contaminents from the cabin atmosphere. In the CO_2 removable equipment, cabin air is passed through an electrochemical CO_2 concentrator where CO_2 is ionically differed from the air to hydrogen supplied from the water electrolysis unit in the O_2 Generation equipment. The mixed stream of H_2 and CO_2 is transported to the CO_2 Reduction equipment where CH_4 (methane) and H_2O are produced in a Sabatier reaction. The water produced is condensed and separated from the residual gases (H_2, CO_2 and CH_4) which are vented overboard. The product H_2O is fed back to the O_2 generation equipment where it is dissociated into O_2 and H_2. The O_2 is delivered back to the cabin and the H_2 is supplied to the CO_2 Removal equipment to complete the cycle. Humidity control is provided to remove excess moisture from the cabin air by a condensing heat exchanger. The condensate is fed to the O_2 generation equipment for recycling.

Proper cabin air composition and total pressure are maintained automatically by the O_2/N_2 controller. It senses the O_2 partial pressure and total cabin pressure and signals the O_2 generator to produce O_2 if the partial pressure is too low and opens the N_2 valves to admit N_2 if the cabin total pressure is too low.

In addition, the ARS contains a trace gas removal system (not shown) to remove trace impurities by absorbants and catalytic oxidation.

G370

ATMOSPHERE REVITALIZATION SCHEMATIC



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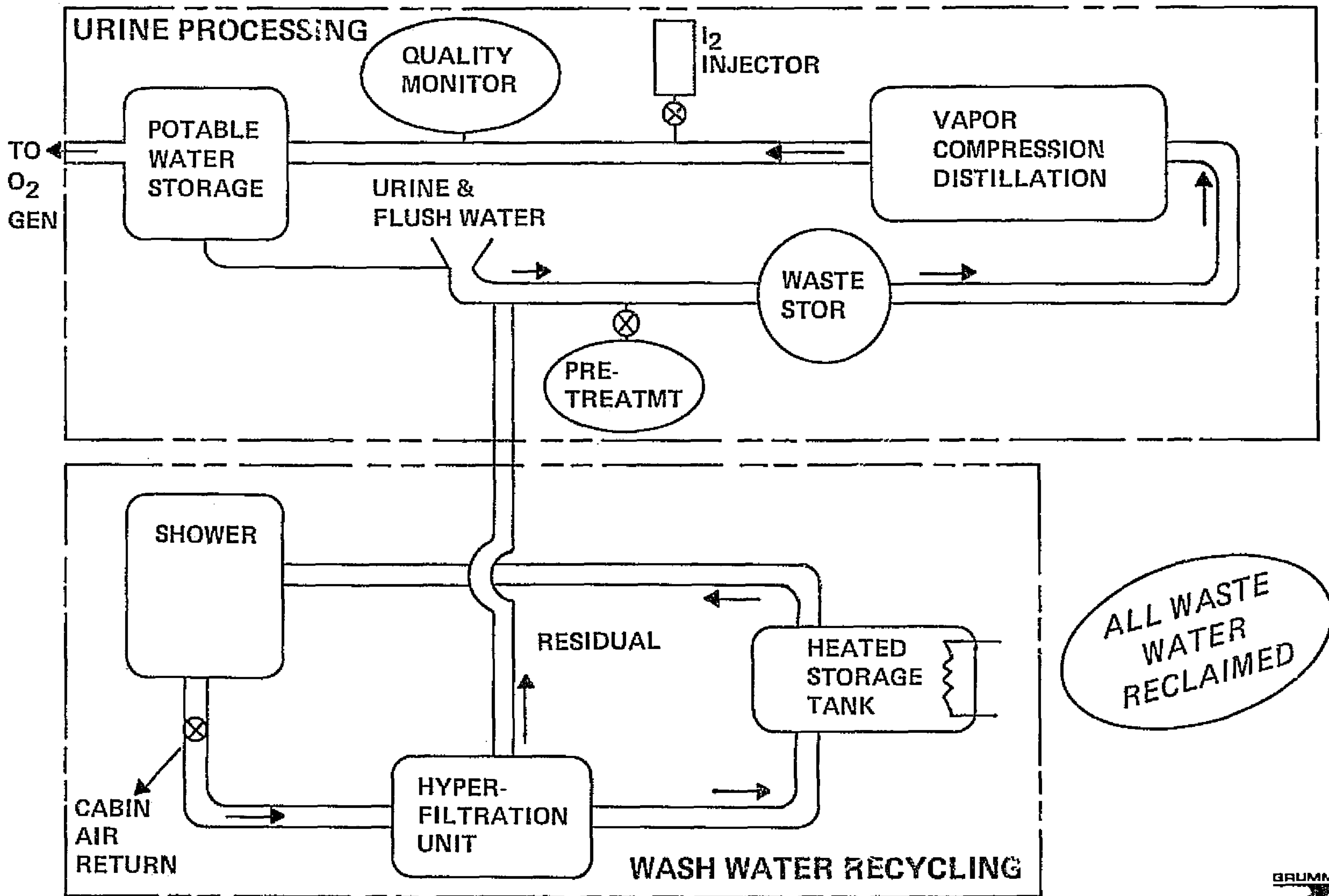
WATER RECLAMATION SCHEMATIC

The two main functions of this section are reclamation of potable water from urine and recycling of wash water for reuse. Urine, collected from the crewmen, is mixed with flush water and pre-treatment chemicals and stored in a tank awaiting processing. Periodically, it is transferred to a Vapor Compression Distillation Processor which utilizes a low temperature phase change process to concentrate the contaminants from the urine into a brine and produce potable water. Concentrated wastes are stored in a waste tank. The product water is further treated with iodine and passes through a quality monitor before being stored.

Wash water reclamation uses a hyperfiltration module to remove contaminants. The product water is stored in a heated tank for reuse in the showers and handwashers. The residual waste water is transferred to the VCD and further porcessed into potable water.

G369T

WATER RECLAMATION SCHEMATIC



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GRUMMAN

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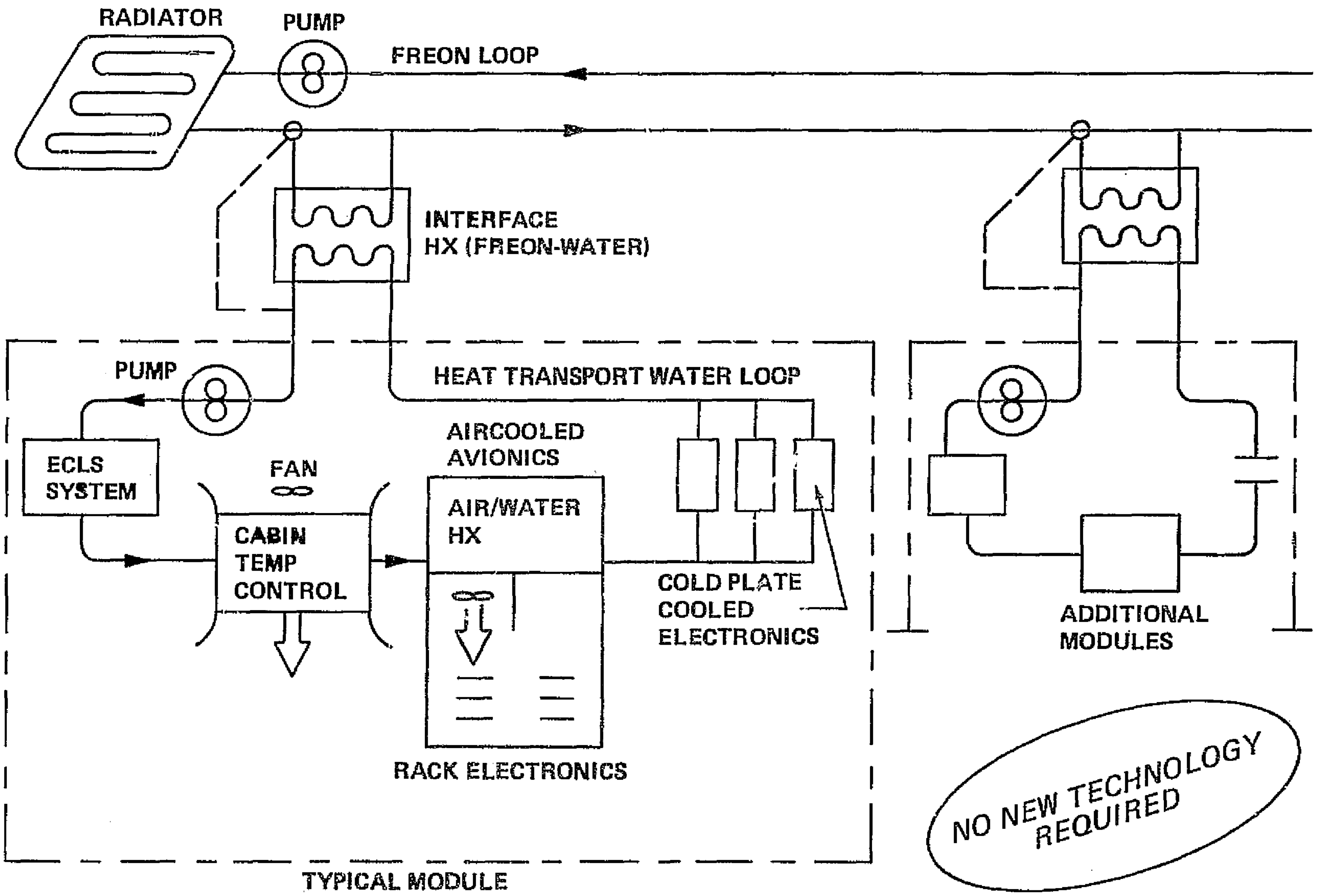
THERMAL CONTROL SECTION

This schematic illustrates the two main areas of the Thermal Control section, the Heat Rejection loop (freon) and the Heat Transport loop (water).

Both sections are of straight forward design and present no major development problem.

G351T

THERMAL CONTROL SECTION



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G-351 (J-116)

PART 3 TASKS

The primary task in Part 3 will be one of subsystem refinement and detail definition of requirements for the selected SCB and program options. One area we feel will have a significant impact on the ECLS cost is that of redundancy. The ECLS subsystem covers a larger number of functions and broad-brush redundancy will result in unnecessary cost and weight. We plan to examine this area and provide a safe, cost effective compromise between duplication and scheduled maintenance.

G353T

PART 3 TASKS

- REFINE SUBSYSTEM CONCEPTS FOR SELECTED SCB OPTIONS

- STUDY TO DETERMINE REDUNDANCY REQMTS & OPTIMUM METHOD TO ACCOMPLISH

  OPTIONS TO BE INVESTIGATED:
  - DUPLICATION OF FULL CAPACITY UNITS
  - MULTIPLE UNITS OF PARTIAL CAPACITY
  - BUILT-IN REDUNDANCY OF CRITICAL ITEMS VS INFLIGHT REPAIR FREQUENCY (SPARES/MAINT PHILOSOPHY)

- GENERATE PROGRAMMATIC DATA
  - DEVELOPMENT SCHEDULES
  - COST

GRUMMAN

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ENVIRONMENTAL PROTECTION

Environmental Protection for the SCB comprises that required for thermal isolation of the modules and radiation protection for the crew.

Thermal isolation is provided by external blankets of hi-performance multilayer insulation supported by fiberglass or other non-conducting standoffs.

No additional material is required for radiation protection in LEO because the basic pressure shell is sufficient to provide full protection. However, at GEO radiation becomes a significant hazard and will require additional shielding. Our preliminary evaluation indicates that total shielding must be equivalent to 300 mils of aluminum plus a .020 inch thick tantalum lining inside the pressure shell.

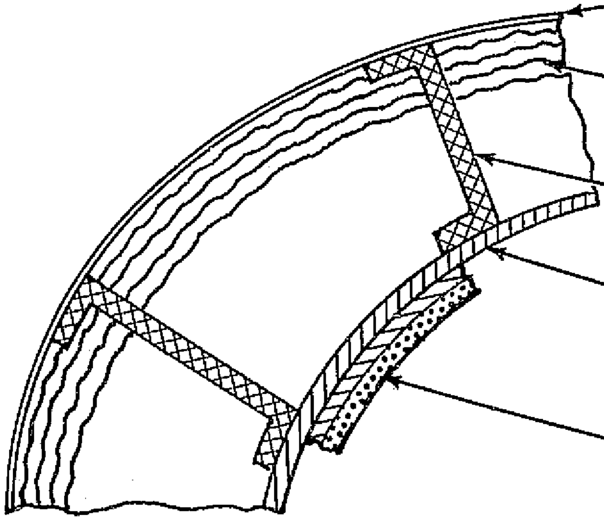
ENVIRONMENTAL PROTECTION

RAD PROTECTION FOR LEO INHERENT IN BASIC SHELL DESIGN

REQUIREMENTS

- RADIATION PROTECTION FOR CREW REQS
  - – MIN EQUV OF 100 MIL ALUM FOR LEO
  - – MIN EQUIV OF 300 MIL ALUM + 20 MIL TANTALUM FOR GEO
- THERMAL ISOLATION OF MODULES 25 LAYERS HI-PERF INSULATION

TYPICAL INSTALLATION



G-378

ELEC PWR SUBSYS (EPS) LOADS – PRGRM OPT 1A/B – LEO/28½° – TIME LATE '80's

This chart shows the fundamental requirements of the Electric Power Subsystem (EPS) in terms of power and redundancy requirements.

Power figures are those for usable loads and losses internal to the Construction Base *only*. Losses and requirements for the Solar Array, Power Transfer Device (Rotary Joint), Battery and Battery Charge Controller are not included.

G-411T

ELEC PWR SUBSYS (EPS) LOADS PRGRM OPT 1A/B-LEO/28½°
TIME ~ LATE '80'S

CONSUMER/HEAT SOURCE	AV PWR-KW STANDBY	AV PWR-KW NOMINAL	SIGNIF AC USE
CREW			
PWR • LOAD SIDE DIST LOSS	0.3	2.9	
• LOAD SIDE COND LOSS	0.6	9.7	
• SOURCE SIDE DIST LOSS			
• SOURCE SIDE COND LOSS			
• STORAGE LOSS	(0.9)	(12.6	
ECLS/WASTE MGMT	2.9	11.5	√
COMM/INSTR/DATA HANDLING	0.4	0.7	
CONT & DISPLAY	0.1	0.4	
ON BOARD C/O	0.1	0.8	
GUID & CONT/PROPULSION	1.0	1.5	√
DOCK/AIRLK/EVA SUIT SVCE		0.5	
ILLUMINATION	0.5	3.0	√
FOOD & HYGIENE		3.1	
RECREATION	(2.1)	0.5(10.5)	√
SPACE MFG • BIOLOGICAL		5.3	√
• MAGNETS		4.6	
• SI RIBBON		2.7	
• MFG DEVEL		5.0(17.6)	
ENG TEST LAB	(SEE NOTE)	13.7	√
CONSTR • AUTO FAB (3)		3.8	
• CRANE		2.0	
• Q/C & C/O LAB		1.0(6.8)	
ORB DEPOT		1.0	
TOTALS	5.9	73.7	

- PROVIDE FO/FO/FS FOR ESSEN (CREW SAFETY) LOADS
- PROVIDE FO/FS FOR ALL OTHER LOADS

NOTE: INCL LIFE SCIENCE (6.7KW), STO (2KW), SOLAR PWR EXPER (5KW)

DC/AC RATIO: 3 TO 1

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G-411 (J-166)

EPS OPTIONS

The four subsections of the EPS subsystem listed in this chart are the areas we have studied and made preliminary option choices.

- "PWR GEN" refers to the primary source of power — in this case, a solar array
- Energy storage devices — i.e., batteries, flywheels, fuel cells, etc. — are used to supply load power during the eclipse portion of each orbit. During the sunlight portion, the primary source must provide this energy as well as that demanded by the vehicle load
- Standby/Emergency Sources are those primary sources and energy storage devices dedicated to crew safety in the absence of all other normally available power. For purposes of this study, this will consist of an 11.7 kw solar array; 8.5 kwh, 20 amp/hr Nickel-Cadmium battery; battery charger; and the requisite dedicated distribution, control and conditioning equipment to supply 5.9 kw load for 7.5 days (Shuttle to LEO)
- The control, distribution and conditioning equipment provides *protection* and *isolation* between a faulted load or bus and all other loads, busses and sources (control); *places* the power where it is needed (distribution); and provides the *power* and *quality* of power required by each user load (conditioning). This section must also provide the redundancy required for each type of load equipment to assure mission and safety requirements are met.

EPS OPTIONS

- PWR GEN (SOLAR ARRAY) CONFIG/VOLT LEVEL
- ENERGY STORAGE DEVICES/CONFIG
- STANDBY/EMERGENCY SOURCES
- CONTROL/DIST/COND TECHNIQUES/CONFIG

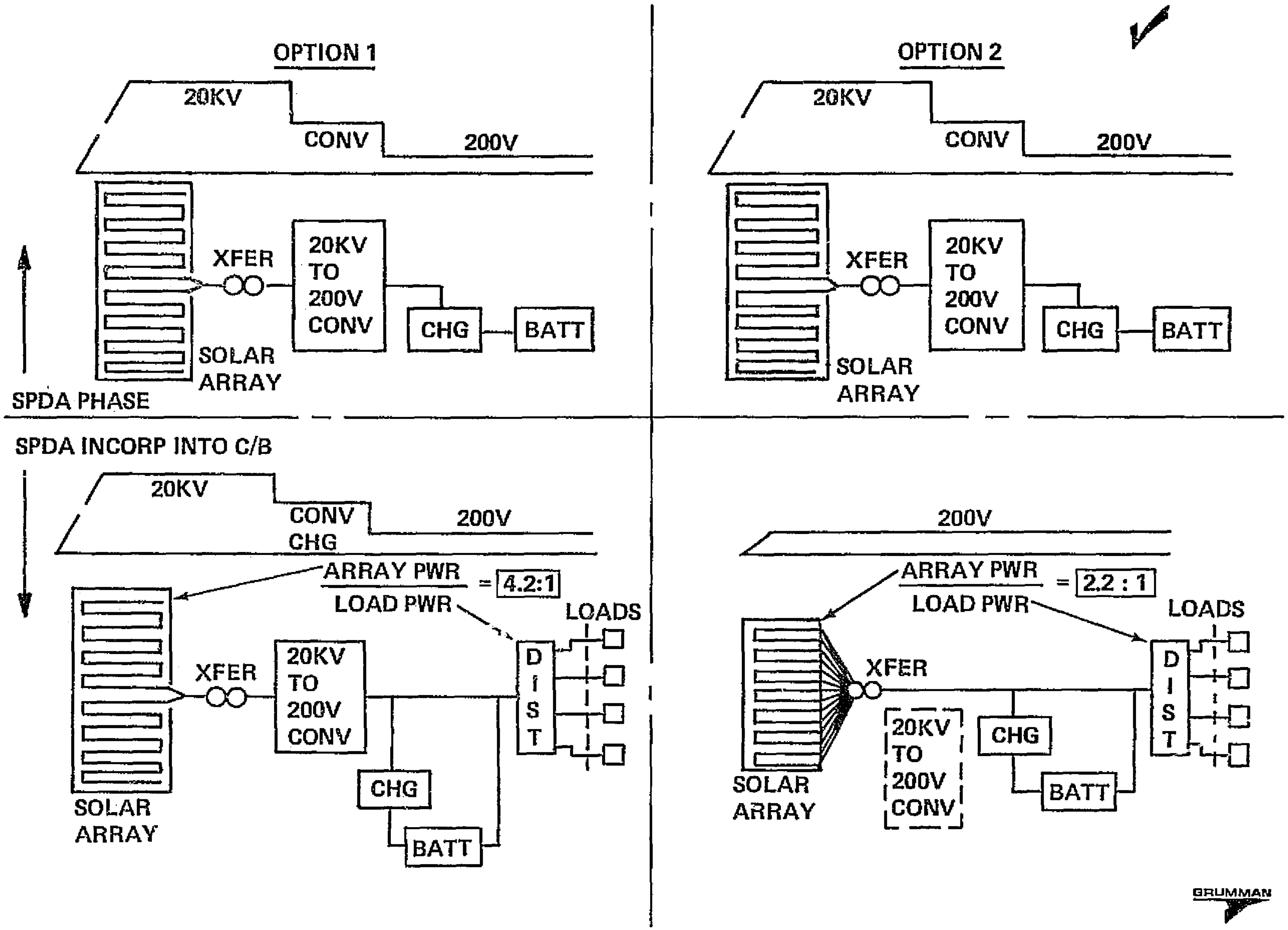
GRUMMAN

SOLAR ARRAY CONFIG OPTIONS

This chart briefly shows the choices available for incorporating the SPDA solar array into the Construction Base.

- Option 1 — in which the voltage converter and battery charger from the SPDA are used — results in a size penalty for the Construction Base array. For this the array must be capable of *300 kw*
- Option 2 — in which the voltage converter is dropped since the array is *restrung* for a 200-volt system — results in an array requirement of only *156 kw* — a substantial improvement. The original SPDA array design, however, must take this internal reconfiguration into account.

SOLAR ARRAY CONFIG OPTIONS



G-404 (J-121)

STORAGE OPTIONS

The various choices available for energy storage are shown in this summary. These are divided into three types: batteries, flywheels and fuel cells.

The current selection – 100 amp/hr Nickel Cadmium cells in a four-cell module – is based on a Grumman development program funded by Johnson Space Center in 1970-1972. This program, if reinstated by Mid-1977, could be completed, including fully qualified hardware and charge controllers, by the end of 1979.

STORAGE OPTIONS

- BATTERIES

TYPE	RATING AMP-HR	DEVEL STATUS	WH/KG	REMARKS
NI-CD	15-45	28-36V QUAL	19-24	SKYLAB, OAO, ELMS, OTHER AF
	50	28V/22 CELL, QUAL INCOMPLETE	22-26	AF/HAC DEVEL
√	100	4 CELL MODULE, COULD QUAL ~ 1980	26-31	JSC/GAC DEVEL
NI-H2	20-100	PART DEVEL, COULD QUAL EARLY '80's	37-46	GSFC/COMSAT DEVEL, EXPT NTS-2 HIGH PRESS CONTAIN PROB
AG-H2	UNK	INITIAL DEVEL QUAL ~ 2000?	80-170	HIGH PRESS CONTAIN PROB

- FLYWHEELS

TIME FRAME	DEVEL STATUS	*WH/KG	REMARKS
1974-1977	REQ. QUAL	10-20	NAR STUDY
1977-1983	REQ DEVEL/QUAL	40	INTERMED DEVEL, MATL SENSITIVE
$>$1983	REQ MATL DEVEL	$\leqslant$72	NAR PAPER STUDY

*FLYWHEEL ONLY, MOTOR-GEN NOT INCL.
OPEN AREAS: GEN SPEED/LOAD CHAR, PEAKING TRANSIENT RESP.

- FUEL CELLS

TYPE	RATING-KW	DEVEL STATUS	ADDL DATA/REMARKS
PRIMARY	4KW 5 KW PK	QUAL FOR SHUTTLE	18KG/KW, REACT. CONS 0.4 KG/KWH, $T_{MAX} = 93^oC$, EFF = 62%, PUMP PWR = 120W. REQ SEP ELECTROL.
REGEN	10KW TO ~ 4 HR	REQ DEVEL/QUAL	59WH/KG (1 HR) $<$ SP. MASS $<$ 177 WH/KG (4 HR) SELF ELECTROL OF PROD H_2O

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STANDBY SOURCE OPTIONS

This chart lists the choices available for dedicated emergency sources. Although we have not yet conducted this study, these would be based on a 5.9 kw requirement for 7.5 days.

G-406T

STANDBY SOURCE OPTIONS

- SOLAR ARRAY/BATT
- PRIMARY BATT (AG-ZN, LM TYPE)
- FUEL CELL
- NUCLEAR
  - THERMOELECTRIC (T/E)
  - BRAYTON CYCLE
  - ORGANIC RANKINE CYCLE
  - STIRLING CYCLE

  RADIO ISOTOPE (238Pu OR 244 Cm) OR URANIUM ZIRCONIUM HYDRIDE (UZrH) HEAT SOURCES

CONTROL/CONDITION/DIST OPTIONS

The choices available in each area of this section of the EPS are outlined in this chart. Covered are the controllers (switch gear) used to perform switching (including power management) and protection functions, bus and wire to route the power to the SCB modules and loads, and that portion of the conditioner complement used to control the batteries.

Although the selections made for the "Strawman" system are self-explanatory, it is important to note that nothing is shown for load conditioners since these designs will be driven by user load requirements. It is only necessary to note in passing that, insofar as possible, all load conditioner designs should be standardized and internally modularized. Certainly common design criteria should be used to a maximum.

G-407T

CONTROL/CONDITION/DIST OPTIONS

- CONTROLLERS (SWITCHGEAR)

	RATING/TYPE	DEVEL STATUS	REMARKS
√	$100V < V < 300V$ $< 30A$	SOME DEVEL ONGOING – – COULD QUAL ~ 1980	SOLID STATE, NASA/AF/NAVY – – DISS & SPEC. WT IMPROVE REQD
√	$100V < V < 300V$ $30A < I < 100A$	REQ DEVEL – – COULD QUAL ~ 1980	HYBRID (ELECTRONICALLY CONTROLLED CONTACTOR)
	$100V < V < 300V$ ALL CURR	MIL-QUAL HDWRE AVAIL.	ELECTROMECH CB, CONTACTORS, RELAYS

DEVEL RATIONALE: REL, SIZE, WT, CONT/PROT ACCURACY

- BUS/WIRE

√	COPPER	AVAIL, QUAL	CURRENT, KNOWN TECH
	ALUMINUM	REQ DEVEL, REQ TERMINATION DEVEL	POSS OXIDATION PROB, SHOULD BE LIGHTER THAN COPPER

- BATT CHG/DISCH

	200V, CHG/DISCH SWITCHING	REQ DEVEL – – COULD QUAL ~ 1980	~ 1.25 TIMES SIZE & WT OF EQUIV 28V UNIT. EFF = 80%
	200V, CHG ONLY SWITCHING	REQ. DEVEL – – COULD QUAL ~ 1980	~ 0.94 TIMES SIZE & WT OF 28V CHG/DISCH REG. EFF = 85%
√	DIGITAL SWITCH SEGMENTED	PARTIAL DEVEL – – COULD QUAL ~ 1980	$\leqslant$ 0.5 TIMES SIZE & WT OF 28V CHG/DISCH REG EFF $\geqslant$ 97%. GAC IN-HOUSE, PWR DEVICES ON ARRAY

DEVEL RATIONALE: REL, SIZE, WT, SOURCE UTIL EFFIC, ON-BOARD LOSS REDUCT

GRUMMAN

FUNCTION BLOCK DIAGRAM – "STRAWMAN" EPS

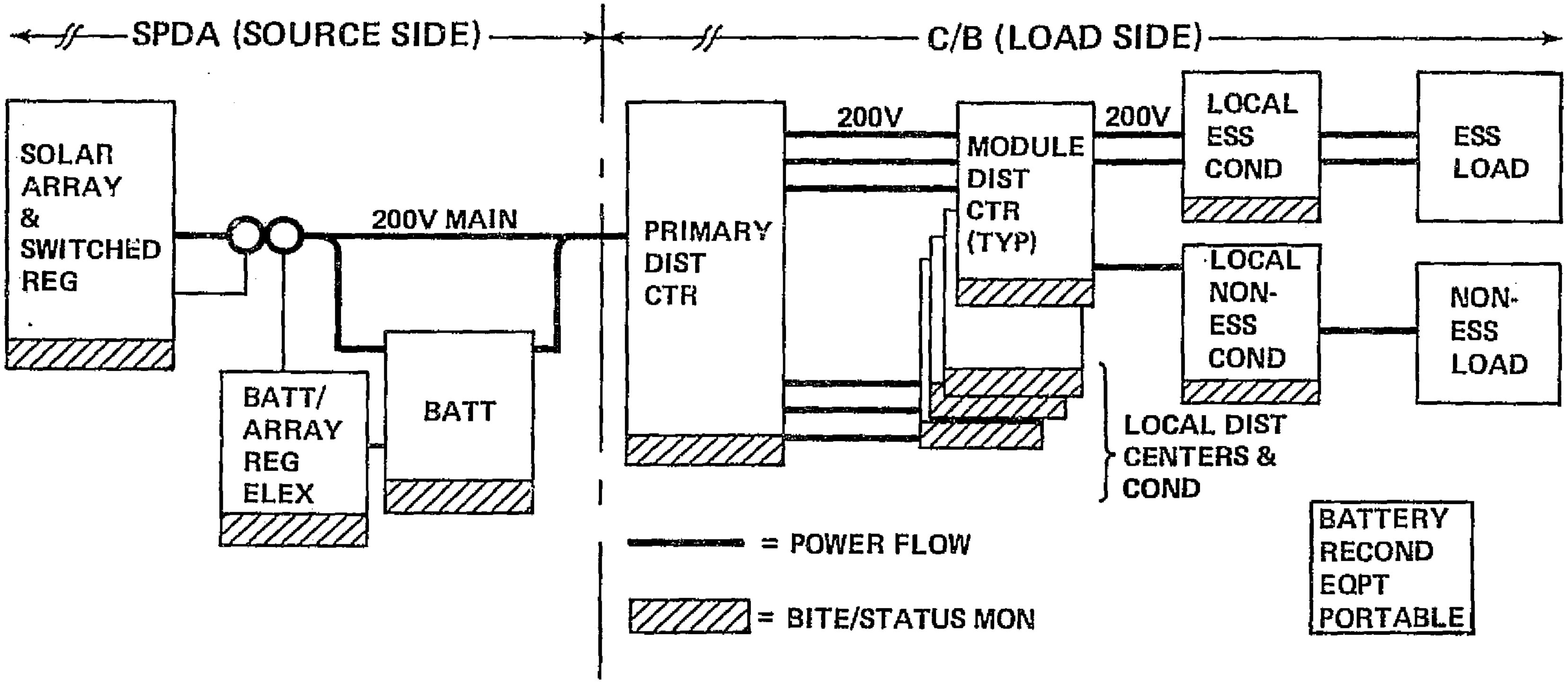
The schematic shows the relationship among the various elements of the "Strawman" EPS, and the power flow from primary and storage sources to user loads.

Although signal flow for power management is *not* shown, a combination of BITE (Built-In Test Equipment) and load demand information would be sent to a central computer whose prime function would be to route power where and when needed within system capability and fault status limits. Crew safety would be maximized and source utilization optimized thereby.

The configuration shown permits load reconfiguration both within the SCB as a whole (user modules may be added and/or subtracted to source limits) and within a module (at the module's own distribution center). In this sense, a "power utility" is established on the "source side" – a concept carried out by means of the "load side" distribution centers and their associated bus configurations. The flexibility both to start small and build to full size, and to alter missions is thus enhanced.

As far as possible, conditioning is done in a load-dedicated fashion. Use of standard function and power module blocks to build the conditioners permits this at minimum cost and maximum utilization.

FUNCTION BLOCK DIAGRAM – "STRAWMAN" EPS



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- BITE/STATUS MON USED TO CONTROL/MANAGE PWR UTIL & PROVIDE DISPLAY & WARNING
- REDUND & COMPUTER CONTROL USED TO PROVIDE FO/FO/FS FOR ESSEN LOADS
- PARTIALLY DECENTRALIZED DIST/CONT – "WALL PLUG" FLEXIBILITY

G-408 (J-125)

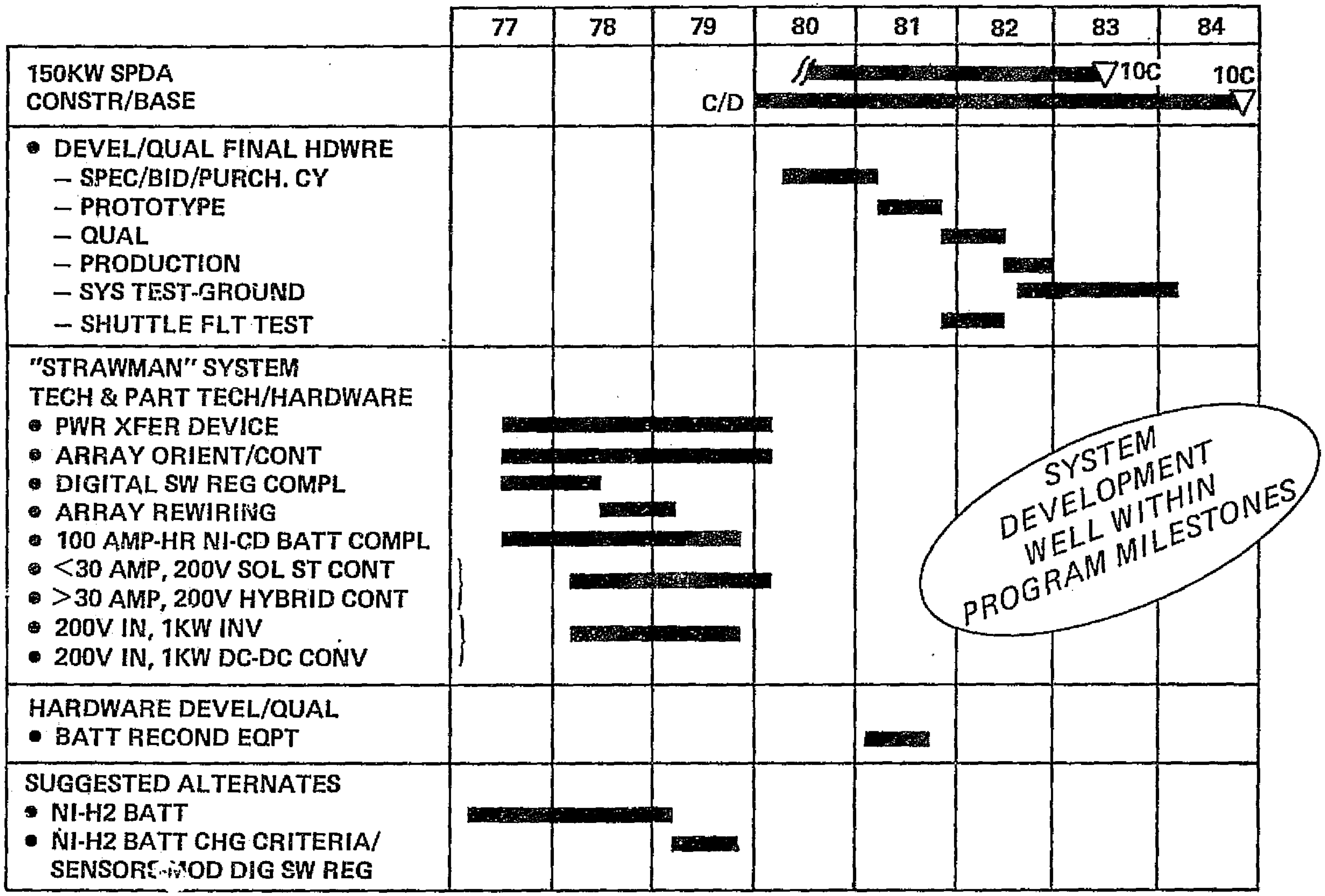
GRUMMAN

EPS DEVELOPMENT CYCLE

As can be seen from the adjacent chart, the development of the EPS technology and flight hardware can be accomplished in ample time to meet program milestones.

G409T

EPS DEVELOPMENT CYCLE



STD PKG CRITERIA PER– NASA/MSFC NAS 8-24690
– NASA/JSC NAS 9-10411

GRUMMAN

G-409 (J-127)

PART 3 TASKS

Our primary task in Part 3 is to definitize the EPS subsystem for the selected SCB configurations and to develop the corresponding programmatics. Part of this task will be to define any STS sortie flights required to verify new configurations.

PART 3 TASKS

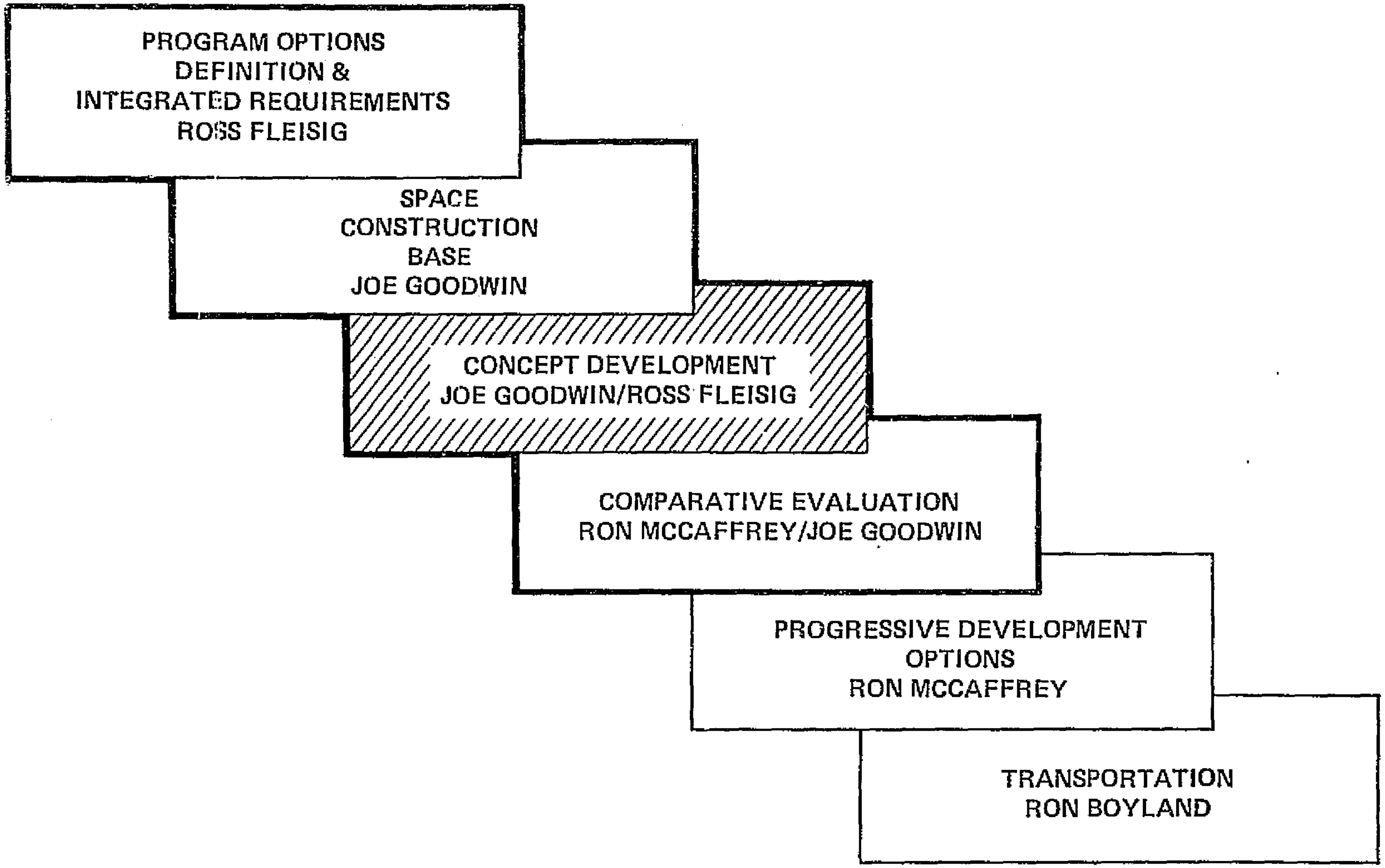
- REFINE SUBSYSTEM CONCEPTS FOR SELECTED SCB OPTIONS

- REFINE DEVELOPMENT REQUIREMENTS/SCHEDULES FOR HARDWARE AND SYSTEM

  – REFINE DETAILS OF SHUTTLE SORTIE TO VERIFY 200V BATTERY CONFIGURATION.

GRUMMAN

VOLUME 2 – PROGRAM OPTIONS



GRUMMAN

ALTITUDE & INCLINATION TRADE APPROACHES

STS payload capability increases to a maximum as altitude drops. However, lower altitude means higher drag. This trade is a main driver in selection of altitude.

Assumptions made in the overall altitude trade are listed on the chart.

The SCB in a 396 km orbit at inclinations above 28½ deg offers an alternative to the current proposed options for performing the STO mission, i.e., Options 2A/B and Option 3. The inclination trade weighs the improved STO performance at high inclinations against the increment in transport costs to support the SCB in these orbits.

G418T

ALTITUDE & INCLINATION TRADE APPROACHES

ALTITUDE TRADE

- MAIN DRIVER IS STS PERF VS DRAG
- LEO SCB AT 28½° INCLN USED FOR TRADE
- FULL ELEVEN YEAR ATMOS. DENSITY CYCLE CONSIDERED
- DRAG CONTINUOUSLY CANCELLED BY THRUST
- COLD GAS & HYDRAZINE THRUSTERS TRADED

INCLINATION TRADE

- MAIN DRIVER IS TRANSPORT COST VS STD COVERAGE
- LEO SCB AT 396 KM ALT USED FOR TRADE

GRUMMAN

G-418

PAYLOAD PENALTY FOR CARRYING EXTERNAL TANK TO ORBIT

The Shuttle Transportation System (STS) External Tank can be carried to 28½ deg inclination orbit with little penalty to the STS payload capability. During normal STS launches the external tank is carried to main engine cutoff (MECO). The additional delta velocity required to carry the tank to orbit is estimated to be:

Delta Velocity Requirement	400 km	500 km
MECO to apogee burn, m/sec	89	121
Circularization at apogee, m/sec	93	116
Rendezvous & docking, m/sec	44	44

It is assumed that all delta V burns subsequent to MECO are performed with the Orbital Maneuvering System (OMS). Pertinent values used in calculating the penalty for orbiting the external tank include:

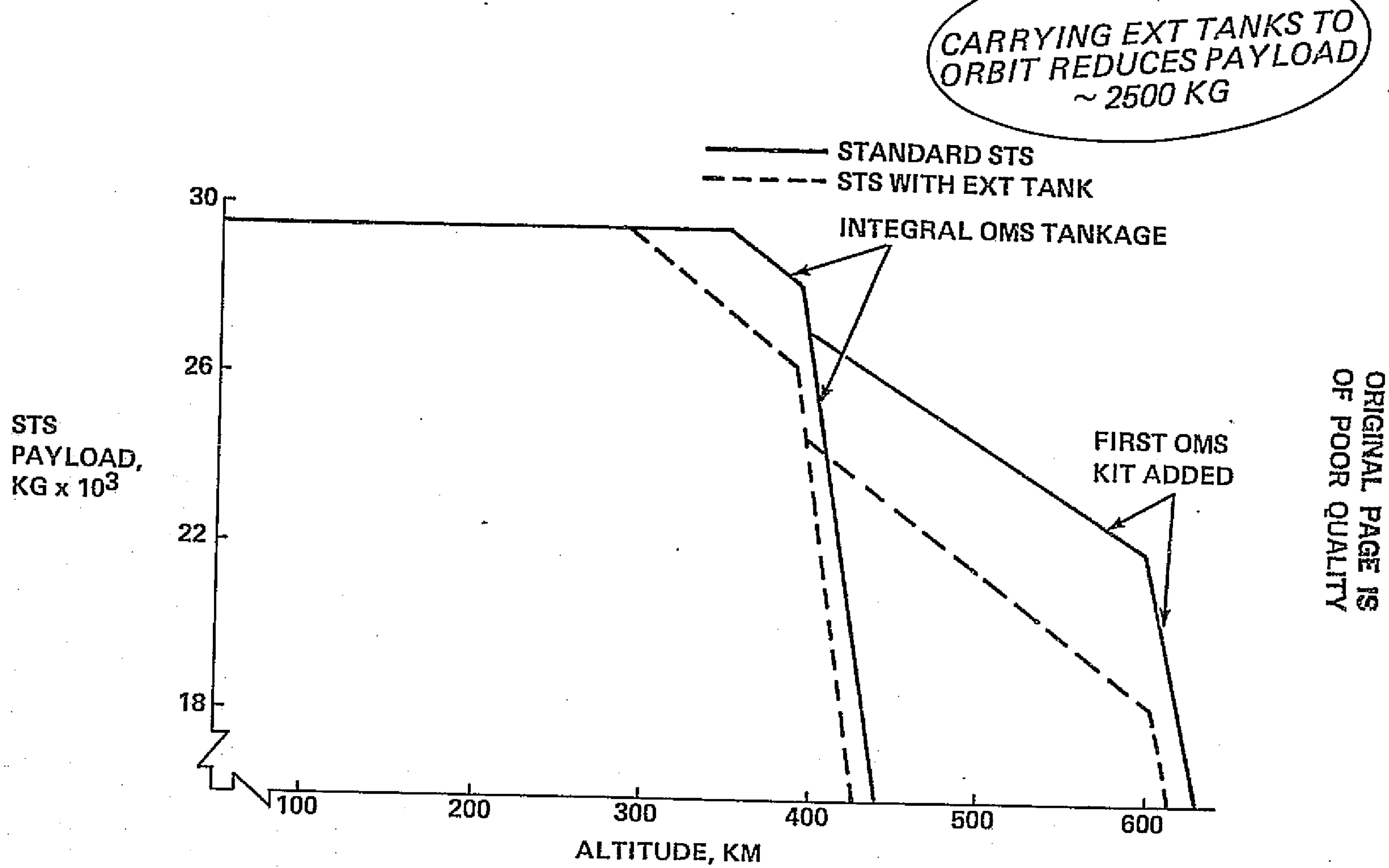
STS weight loss during coast to apogee	=	2,734 kg
STS weight at MECO	=	148,493 kg
Ext Tank weight at MECO	=	34,561 kg
OMS engines nominal I_{sp}	=	312 sec

Based upon the foregoing assumptions, the STS payload penalty for carrying the External Tank to a 400 km-28½ deg orbit (including rendezvous) is calculated to be 2463 kg. 500 km penalty is 3037 kg.

G-331T

PAYLOAD PENALTY FOR CARRYING EXT TANK TO ORBIT

28½ DEG INCLINATION – DELIVERY & RENDEZVOUS



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GRUMMAN

G-331

C_DA vs TIME – TYPICAL LEO SCB SOLAR ARRAY AREA AVERAGED

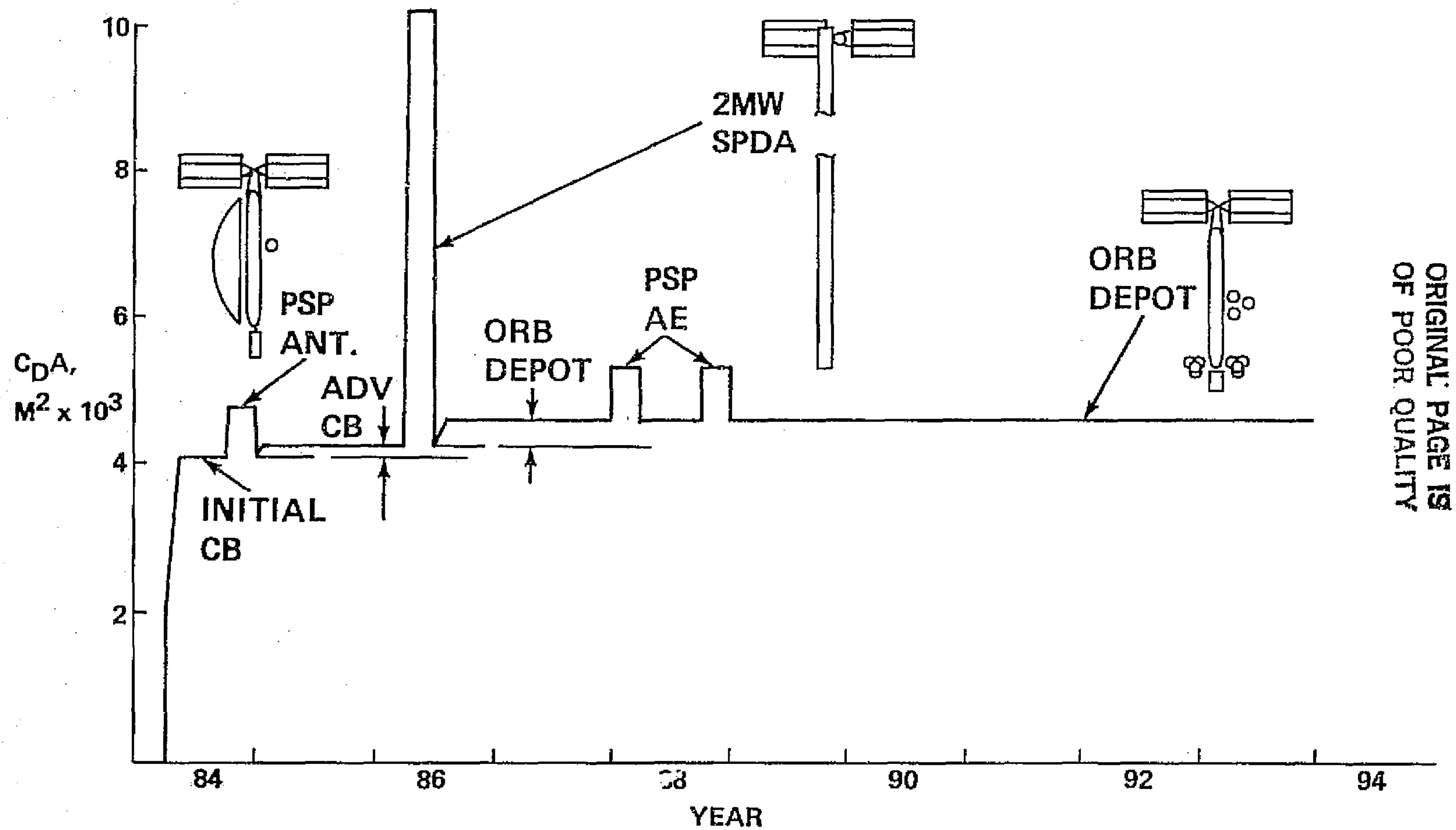
C_DA values were calculated for the evolution of the SCB from its initial phase through its use as an Orbital Depot. Drag coefficient value of 2 was used throughout and the areas for the various configurations averaged the solar array area in each case. The peaks reflect additional drag areas due to construction activities.

C-3

G318T

C_DA VS TIME – TYPICAL LEO SCB

SOLAR ARRAY AREA AVERAGED



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GRUMMAN

G-318

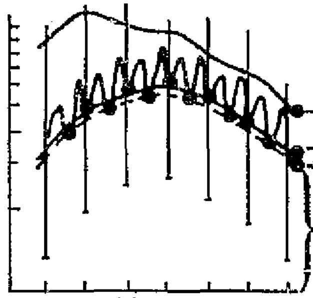
DYNAMIC PRESSURE VS YEAR AND ALTITUDE

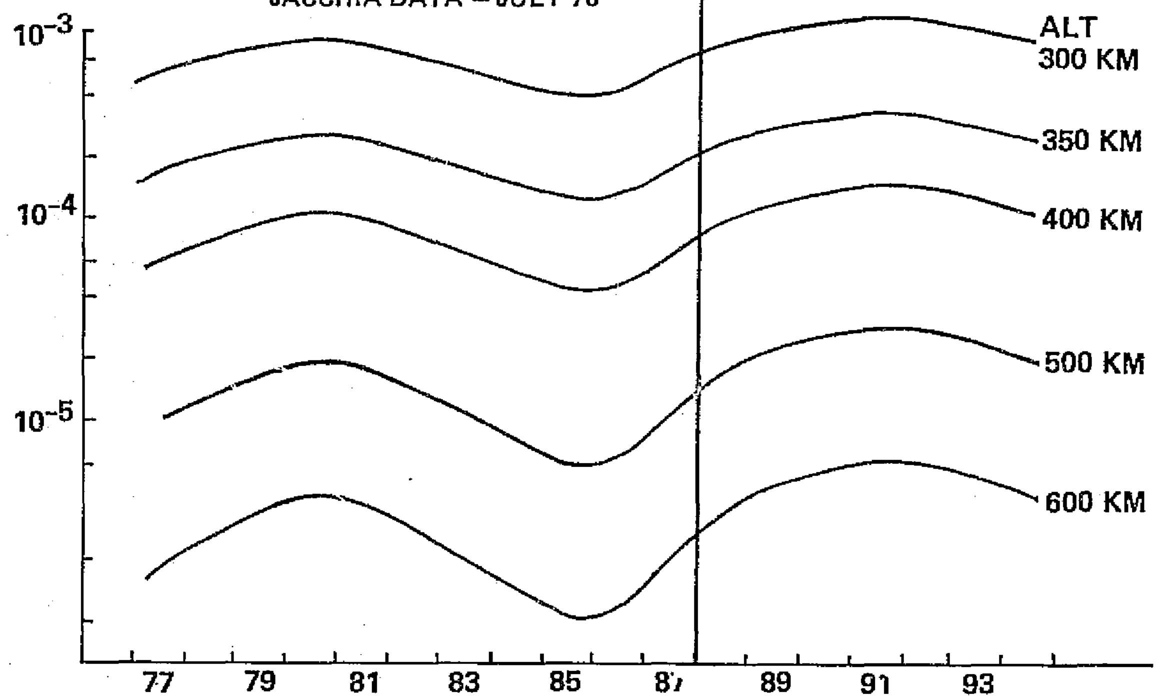
This is a plot of dynamic pressure variations for relevant altitudes at 28½ deg inclination. The time period is that covered by the study. The plot is based on a Jacchia model of atmosphere density and reflects nominal atmosphere density on January 1st each year at 1500 hours. The model information only covered the years up to the end of 1987. The plot was therefore extrapolated beyond that date assuming an 11-year cycle.

The insert plot gives an example of typical daily variations of density.

G313T

DYNAMIC PRESSURE VS YEAR & ALTITUDE





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GRUMMAN

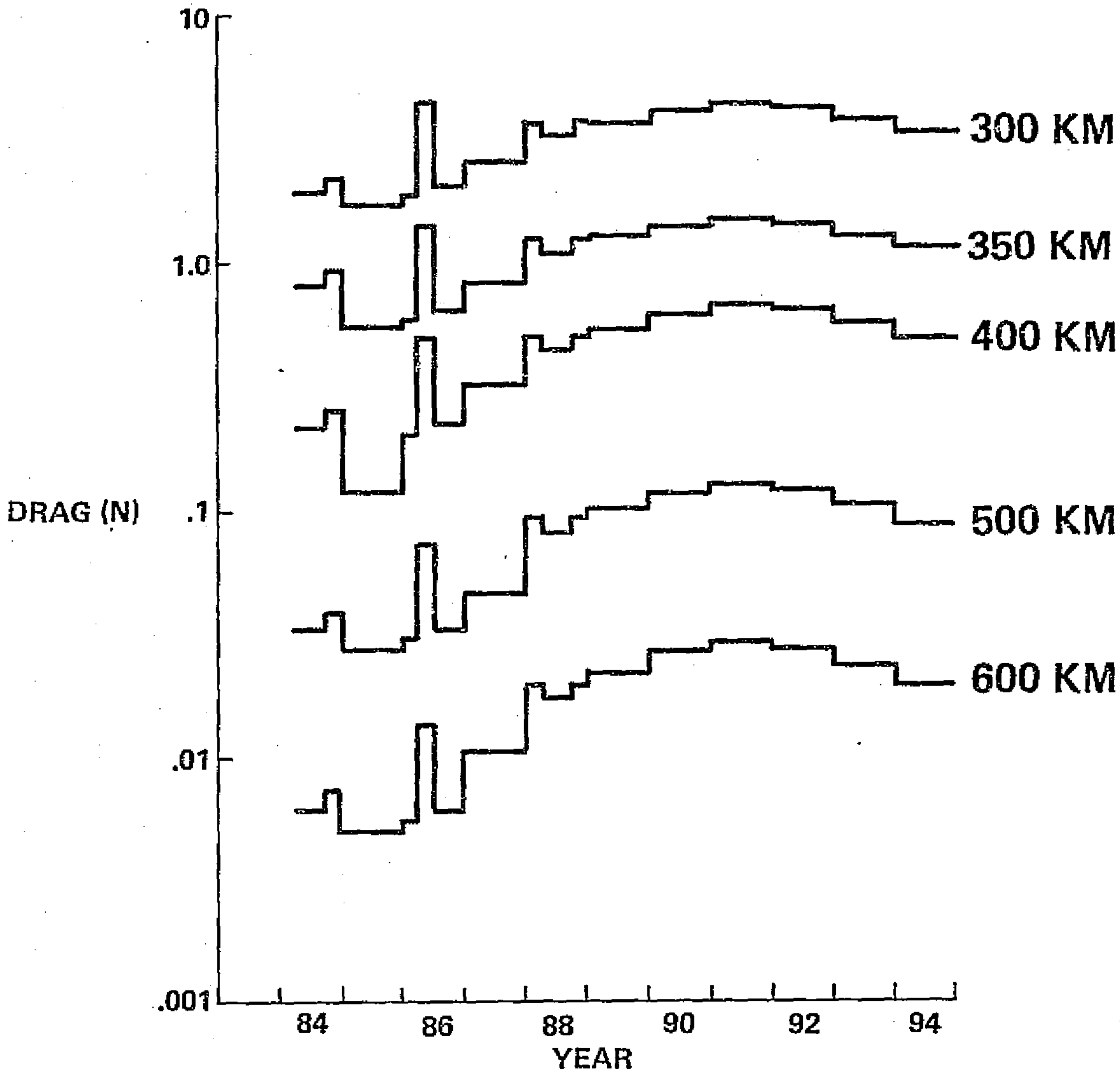
DRAG VS TIME VS ALTITUDE TYPICAL LEO SEB

The two preceding charts are combined by multiplying the C_DA by the dynamic pressure at each of the five candidate altitudes for the years 1984 through 1994. This gives drag as a function of time for these altitudes.

G314T

DRAG VS TIME VS ALTITUDE

TYPICAL LEO SCB



GRUMMAN

PAYLOADS TO LEO EXCLUDING RCS PROPELLANT

Two launch-to-orbit phases are covered on this chart.

Firstly, the total payloads necessary to build up the SCB to Advanced status are shown in yearly increments.

Secondly, the routine mission operations yearly payloads are shown in four categories. These categories, in fact, cover the following missions:

<u>Science</u>

- Life Sciences
- STO

<u>Construction</u>

- PSP
- SPDA

<u>Space Manufacturing</u>

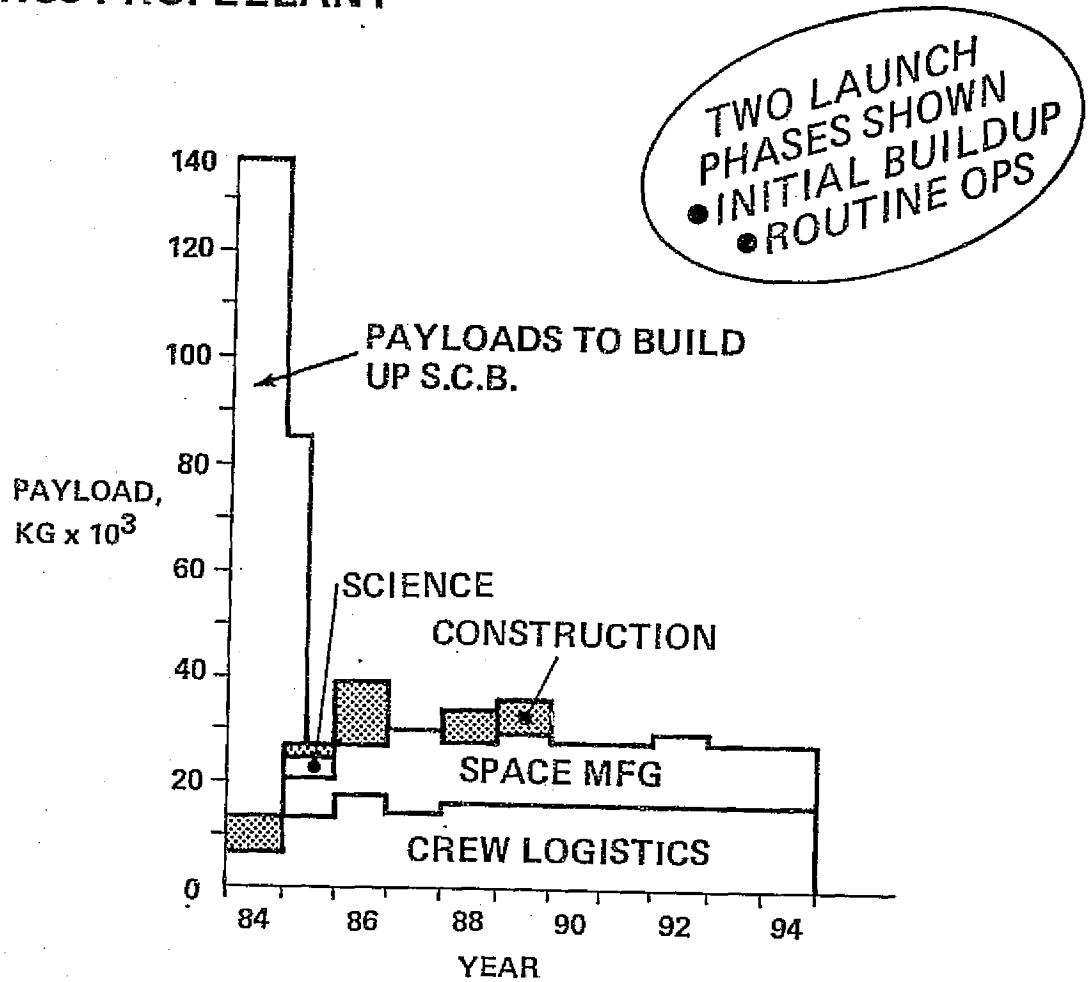
- Branch modules
- Material resupply

<u>Crew Logistics</u>

Attitude control resupply payloads are excluded from this chart. They are dealt with on another chart since they vary with altitude and propellant system.

G317T

PAYLOADS TO LEO
EXCLUDES RCS PROPELLANT



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GRUMMAN

G-317

FLIGHTS/YEAR FOR STATION GROWTH & RESUPPLY ASSUMING ATTITUDE CONTROL USES HYDRAZINE PROPULSION

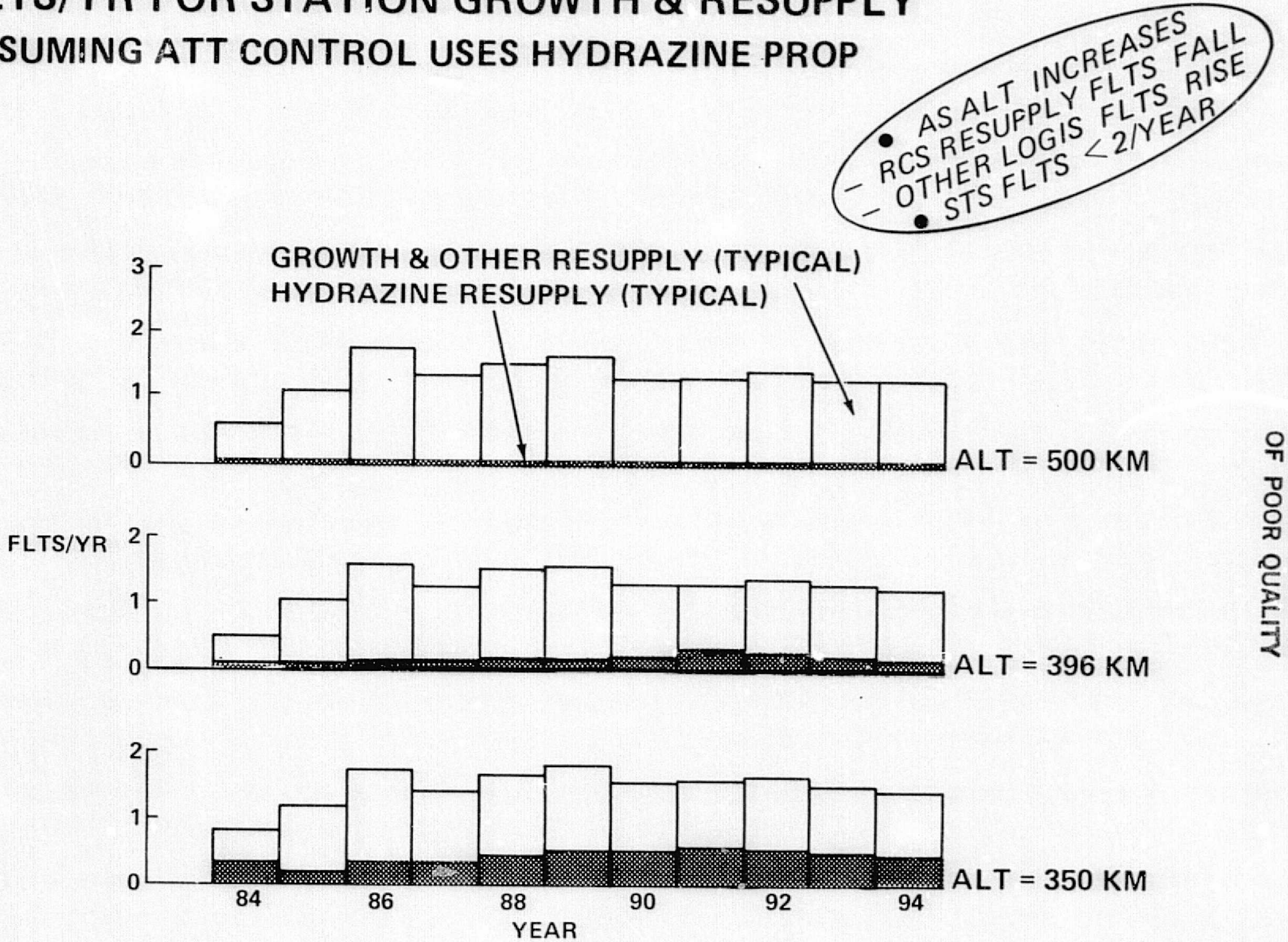
Originally, four propellant systems were considered for attitude control. These were: cold gas, hydrazine, resistojet and ion propulsion. As reported in November 1976 at the program review, cold gas optimum altitude was 500 km. The three more exotic systems had a common optimum altitude of about 400 km with the number of Shuttle resupply flights about the same. The cold gas and hydrazine systems were selected for further study.

Considering the hydrazine system, this chart shows the fall in propellant resupply flights as altitude increases. As can be seen, the flights for growth and other resupply rise with altitude since, although the payload weight is common, shuttle capability falls as altitude rises. Propellant resupply is not a particularly significant proportion of the total flight pattern and, in no case do shuttle flights required for propellant resupply exceed two per year.

G315T

FLTS/YR FOR STATION GROWTH & RESUPPLY

ASSUMING ATT CONTROL USES HYDRAZINE PROP



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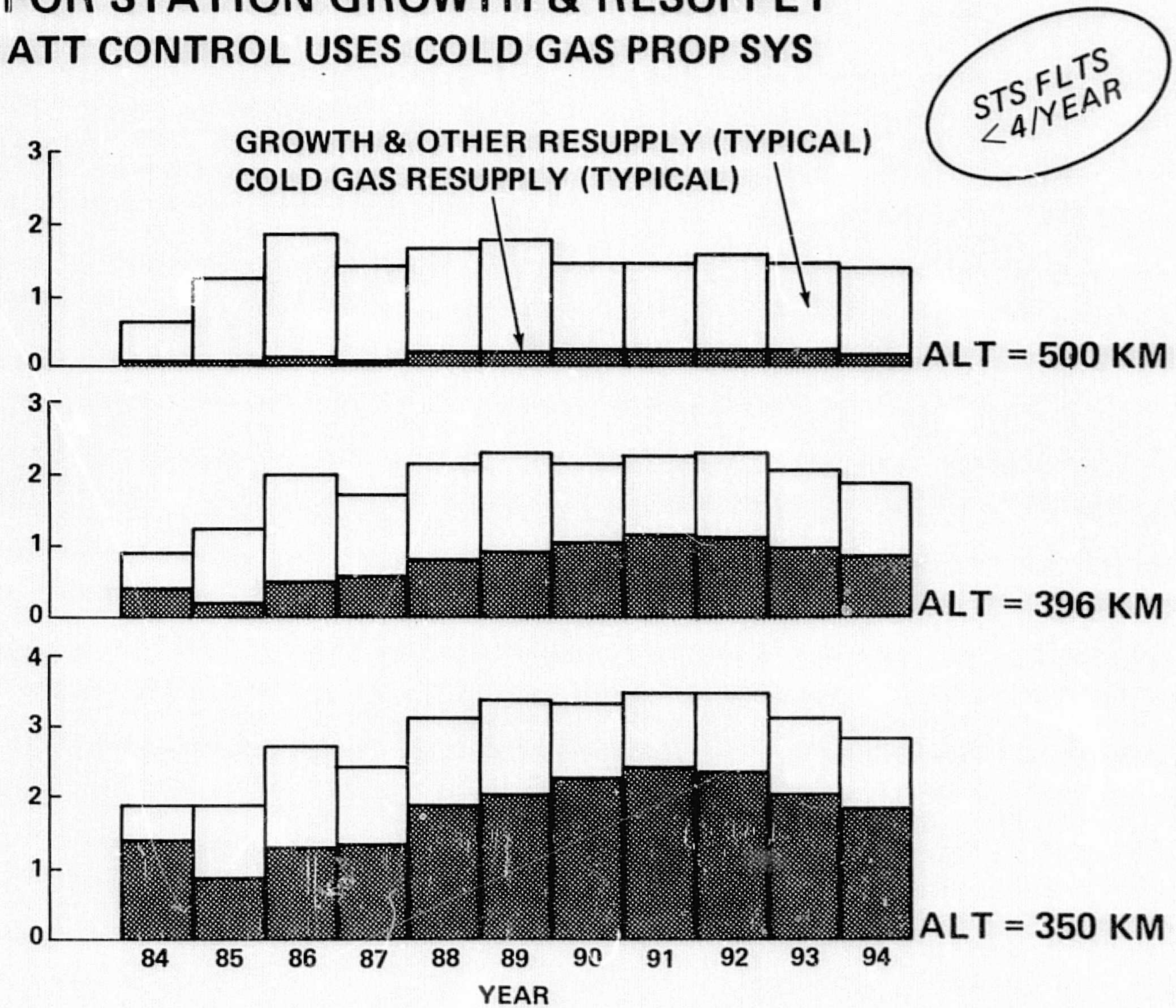
GRUMMAN

FLIGHTS/YEAR FOR STATION GROWTH AND RESUPPLY ASSUMING ATTITUDE CONTROL USES COLD GAS PROPULSION SYSTEM

Two categories of resupply are shown on this chart. Cold gas attitude control propellant resupply flights reduce as altitude increases. Flights for growth and other resupply rise with altitude, since, although payload weight is common, Shuttle capability falls as altitude rises. For the 350 km and 396 km altitudes, propellant resupply is a significant proportion of the total, although the flights per year never exceed four.

G316T

FLTS/YR FOR STATION GROWTH & RESUPPLY
ASSUMING ATT CONTROL USES COLD GAS PROP SYS



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GRUMMAN

G-316

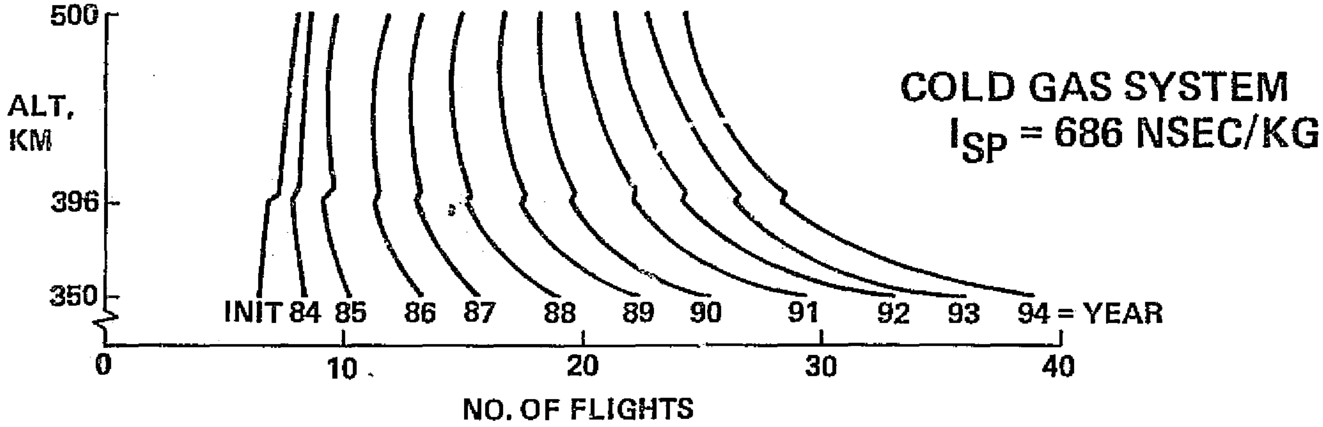
TYPICAL LEO SCB CUMULATIVE STS FLIGHTS vs ALTITUDE FOR TWO RCS PROPELLANTS

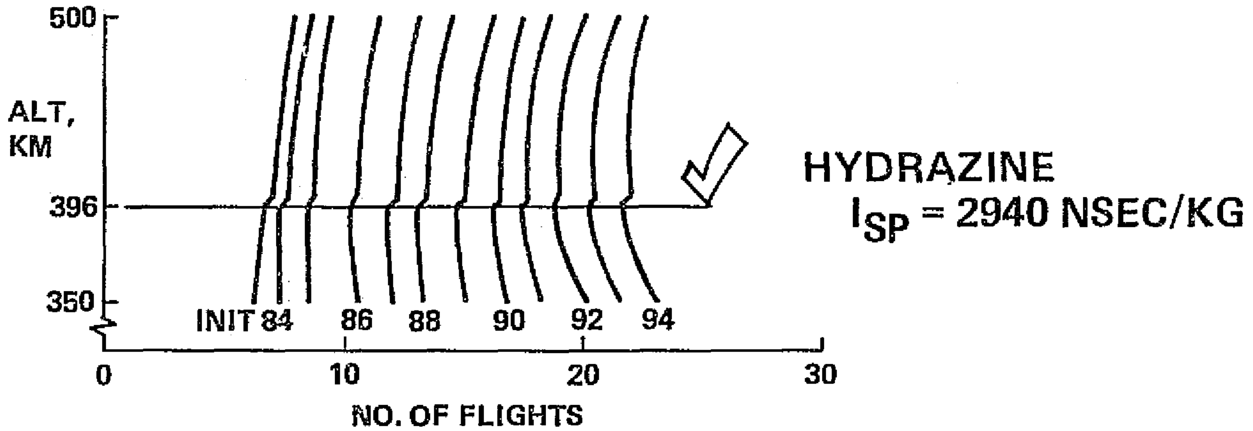
The preceding two charts deal with total resupply flights for hydrazine and cold gas attitude control systems. Combining each of the charts with the number of flights necessary for initial building of the SCB gives a cumulative total of STS flights for each system at various relevant altitudes over the time period 1984-1994.

The hydrazine system gives the least number of flights at these altitudes with the bucket in the curve at about 400 km altitude.

G319T

TYPICAL LEO SCB
CUMULATIVE STS FLTS VS ALT FOR TWO RCS PROPELLANTS





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GRUMMAN

G-319

LEO ALTITUDE MAINTENANCE

As an example of requirements for maintaining the SCB in 396 km orbit, the advanced base is considered and the thrust identified.

Without positive action, the base would lose 0.75 km altitude during the first day. Firing thrusters once per day to maintain altitude requires a total thrust of 1037 N. Four firing units of 220 N each are selected as baseline.

G397T

LEO ALTITUDE MAINTENANCE

- ADVANCED CONSTRUCTION BASE WILL LOSE 0.75 KM ALTITUDE AFTER THE FIRST DAY
- TO MAINTAIN 396 KM ALTITUDE, RCS THRUSTERS WILL BE FIRED ONCE PER DAY

  – THRUST = $\frac{\text{IMPULSE}}{\text{BURN TIME}} = \frac{\text{DRAG X ORBIT TIME}}{\text{BURN TIME}}$

  – DRAG VARIES FROM 0.12 TO 0.68 N OVER LIFE OF ACB DURING OPTION 2B

  – TO REALIZE I_{SP} OF 230 SEC, AT LEAST 10 SEC OF BURN TIME FOR THRUSTERS MUST BE USED

  – TOTAL THRUST = $\frac{(0.12)\ (3600 \times 24)}{10} = 1037$ N

- THRUSTER SELECTION
  – FOUR AFT FIRING UNITS OF 220 N (50 LB) EACH SELECTED
  – THIS THRUST LEVEL CORRESPONDS TO 12 SEC BURN TIME
  – HIGHER DRAG LEVELS REQUIRE MORE BURN TIME
  – NO AND LEVEL OF THRUSTERS ARE COMPATIBLE WITH STAB AND CONTROL, SLEW AND SUBSYSTEM REDUNDANCY REQUIREMENTS

GRUMMAN

ALTITUDE TRADES CONCLUSIONS

Considering the LEO SCB, 396 km is the optimum altitude with hydrazine as the attitude control propellant. As discussed in a previous chart, hydrazine results in the minimum number of shuttle flights for total resupply. No OMS kits are necessary to attain 396 km and maximum cargo bay length and volume are available. A pressurized module, 15.75 m long can be accommodated in the cargo bay and becomes the standard module. STS flights to resupply propellants to a LEO SCB never exceed two per year. When geostationary operations are included, the additional logistics result in nearly four STS flights per year.

Altitude for the base at high inclination LEO is governed by the desire to use the 15.75 m long module. This means that no OMS kits can be carried in the cargo bay, which results in a maximum altitude of about 350 km.

G417T

ALTITUDE TRADES CONCLUSIONS

LEO SCB

- 396 KM IS OPTIMUM ORBITAL ALTITUDE WITH HYDRAZINE ATT CONTROL
  - MIN SHUTTLE FLTS FOR TOTAL RESUPPLY
  - NO ADDITIONAL OMS KIT TO ACHIEVE MAX PAYLOAD
  - HENCE, MAX USE OF CARGO BAY LENGTH (15.7M MODULE) & VOL
  - LEO OPS, STS LOGISTIC FLTS NEVER EXCEED TWO/YEAR
  - WHEN GEO OPS INCLUDED (OPTIONS 1A/B & 3), FLTS APPROACH FOUR/YEAR

OPTION 3 HIGH INCN BASE, LEO

- TO RETAIN 15.7M LONG COMMON MODULE, ALTITUDE AT APPROX 85° INCLN. MUST NOT EXCEED 350 KM

GRUMMAN

LOW EARTH ORBITS FOR STO-INCLINATION TRADES

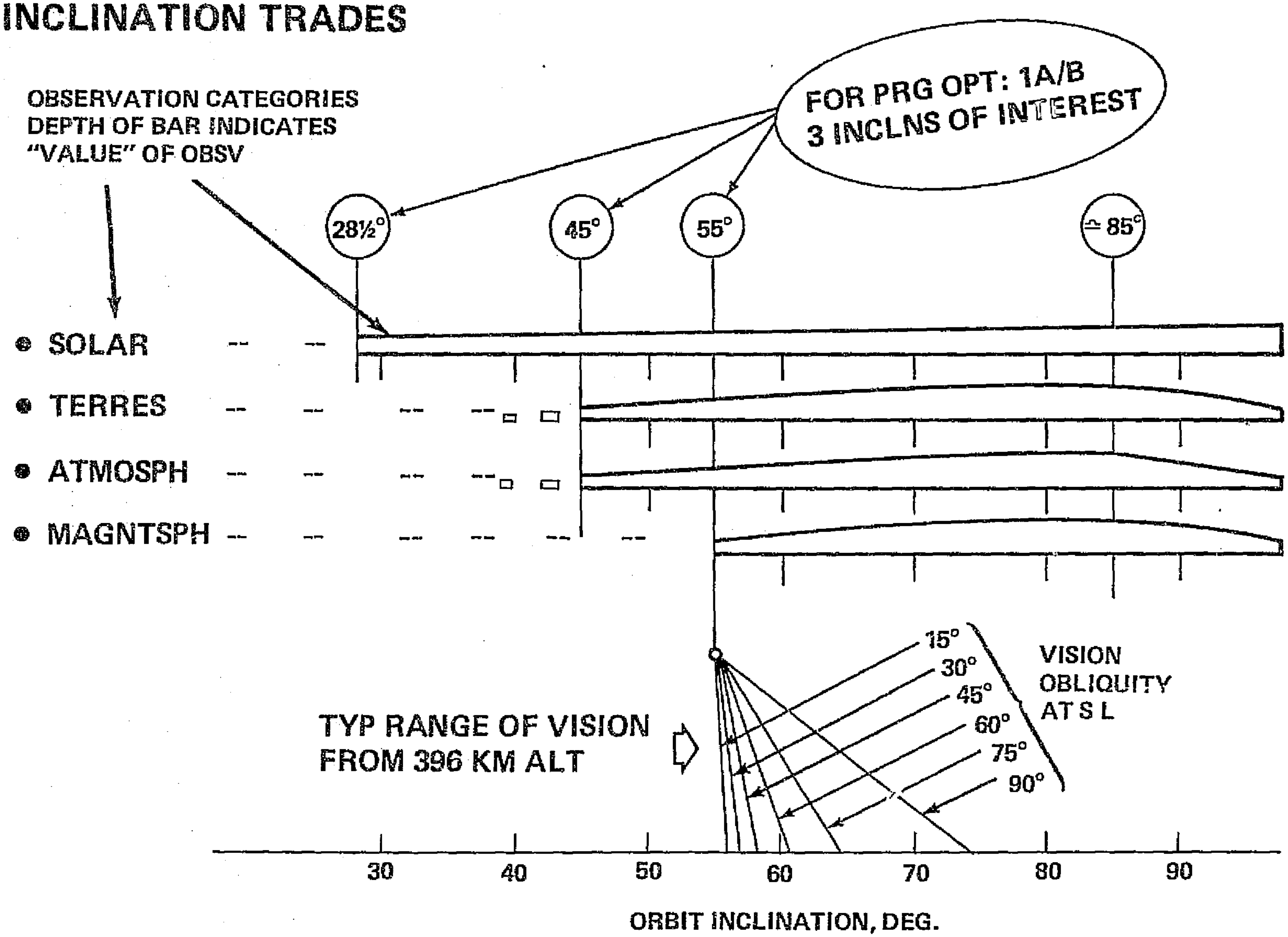
An alternative to conducting solar and terrestrial observations from geo-stationary orbit (Option 2A/B), or from a dedicated high inclination low earth orbit (Option 3), is the concept of placing the Space Construction Base (SCB Option 1A) in a low earth orbit of sufficient inclination to perform a useful Solar Terrestrial Observatory (STO) mission.

The chart illustrates the manner in which the coverage of the four STO observation categories varies with orbital inclination and selects the 28½ deg, 45 deg, and 55 deg inclinations for this trade.

From the orbital altitude of 396 km, additional lateral coverage of earth is available depending on the obliquity of the line of sight (declination of line of sight from local vertical). For example, in a 55 deg inclined orbit (considering 60 deg obliquity as acceptable), visual coverage would extend to 60 deg north and south latitudes. Such coverage would include; to the north, Leningrad, the Bering Straits and the southern tip of Greenland; to the south, Cape Horn, South America.

G373T

LOW EARTH ORBITS FOR STO
INCLINATION TRADES



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GRUMMAN

G-373

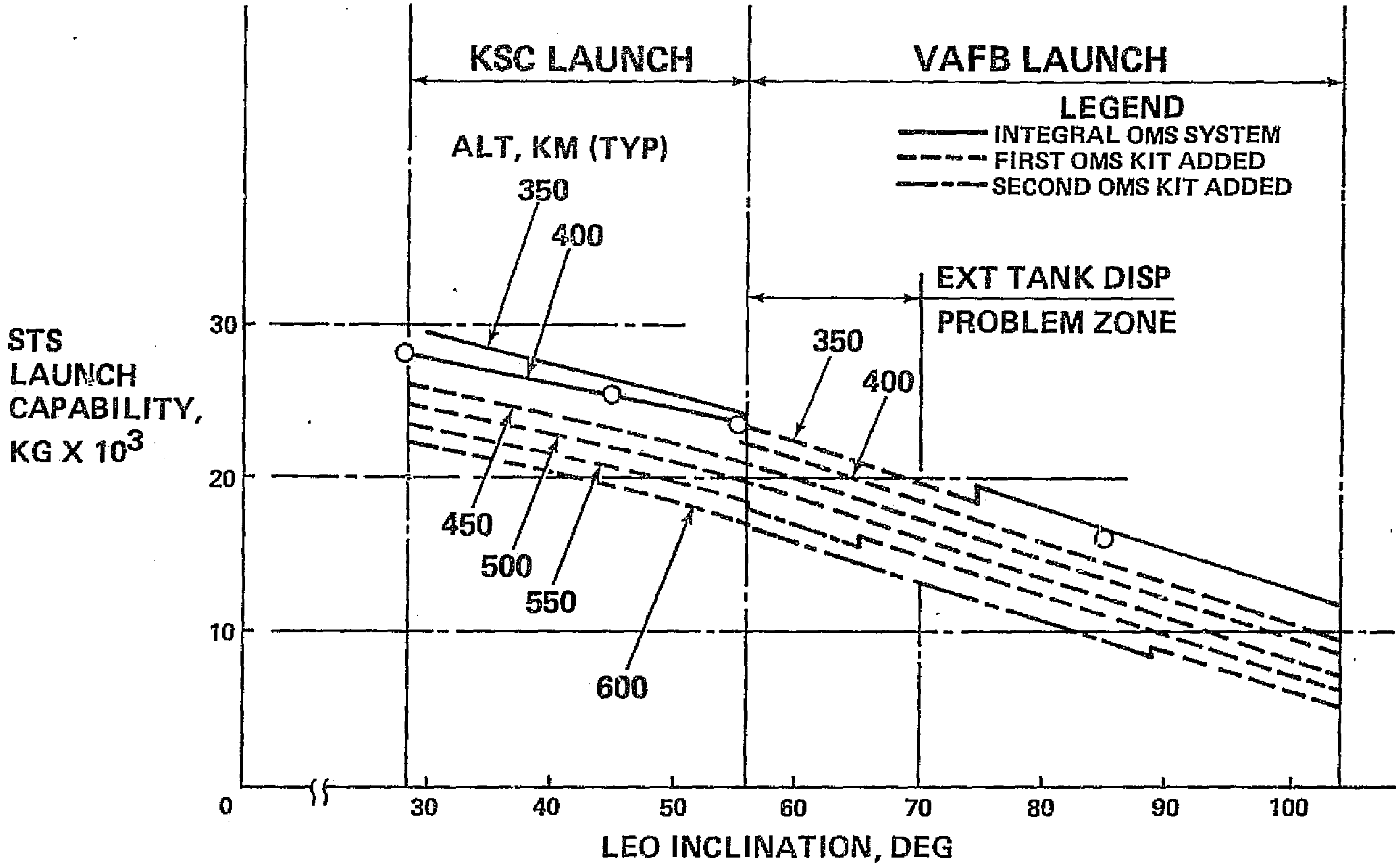
STS PERFORMANCE vs INCLINATION AND ALTITUDE

The source of these data is the Space Shuttle System Payload Accommodations, Volume XIV, Revision D. It shows the payload delivery and rendezvous capability of the STS for various orbital altitudes and inclinations.

Note that for the orbital altitude (396 km) and inclinations considered in this trade, no additional OMS kits are required and the full payload bay volume is available.

G347T

STS PERFORMANCE VS INCL & ALT



GRUMMAN

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G-347

NUMBER OF STS FLIGHTS TO SUPPORT TRANSPORT TO GEO vs INCLINATION

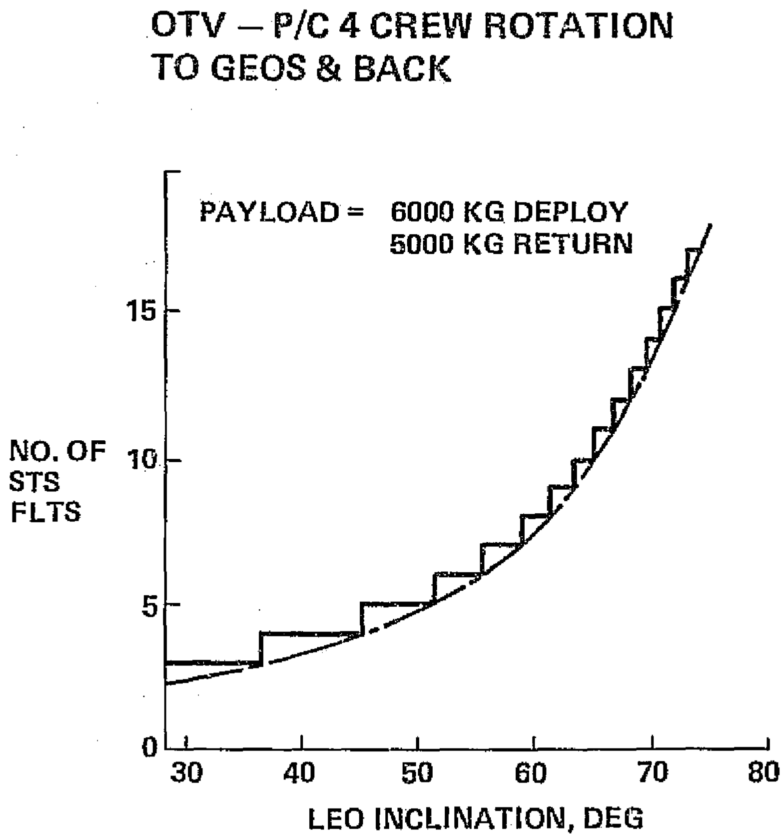
As the SCB orbital inclination is increased, the OTV and IUS launches to GEO require additional Δ V to accommodate the orbital plane change to GEO stationary (zero degree inclination). Thus additional STS flights to LEO are necessary to support the LEO to GEO traffic model.

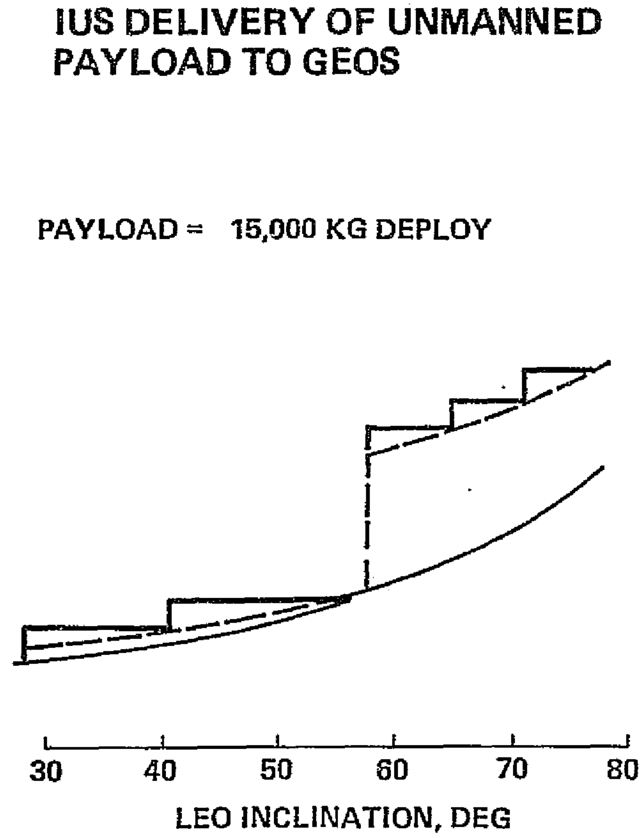
Inclinations up to approximately 56 deg can be handled by the OTV within its six tank cluster configuration. Beyond that, consideration must be given to multi-launches or staging.

An abrupt increase in number of STS flights to support the IUS launches occurs at an inclination of approximately 56 deg. With the reduction of STS launch capability at this inclination the orbiter can deliver only one IUS per flight. For the three orbital inclinations of interest the full launch capability of the orbiter is available.

G346T

NO. OF STS FLTS TO SUPPORT TRANSPORT TO GEO VS INCL





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GRUMMAN

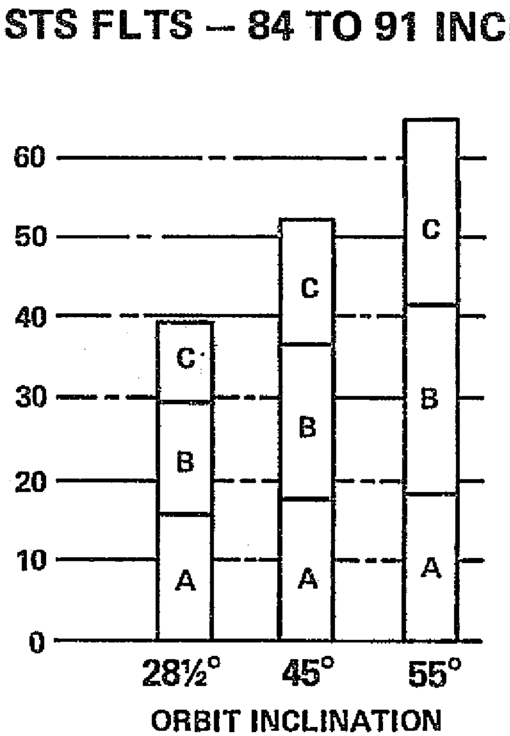
LEO SCB (OPTION 1A) TRANSPORT COSTS vs ORBIT INCLINATION

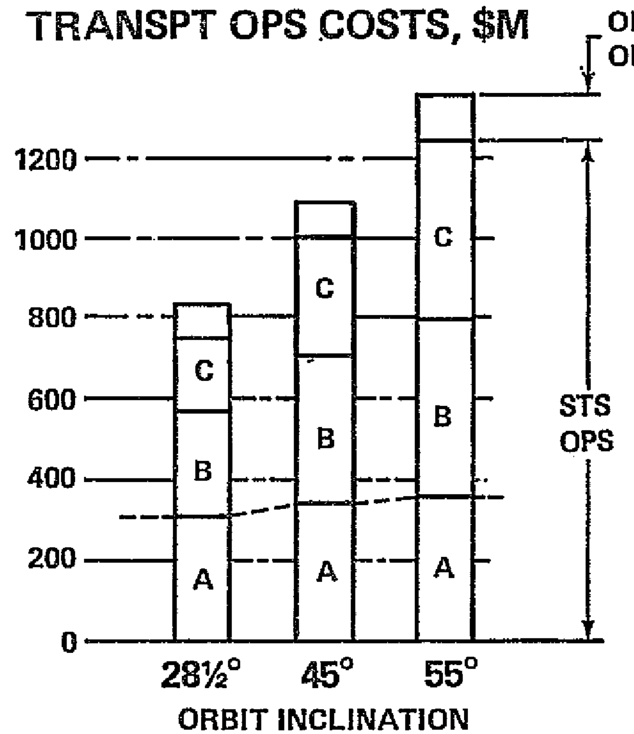
The number of STS flights in the 1984-1991 period to support the SCB construction and the IUS and OTV activities for the three orbital inclinations of interest are converted to transport operations cost at the rate of $19.3M per STS flight.

G402T

LEO SCB—OPTION 1A
TRANSPORT COSTS VS ORBIT INCLINATION

MAJOR COST DRIVERS—
• STS PERFORMANCE
• GEOS OPS





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LEGEND

A — SCB BUILD UP & GROWTH – ROUTINE LEO SUPPLIES STO, LIFE SC, SPACE MANUF SUPPORT

B — PSP 1, 2 & 3

C — 2 MW SPDA – MANNED GEOS. SORTIES

GRUMMAN

G-402

LEO INCLINATION OPTIONS

The chart summarizes the Solar Terrestrial Observatory (STO) performance at selected LEO inclinations, and the increment in program costs to provide this performance.

At the lower inclinations, alternate means such as free flyers are required to provide high quality data for all but the solar STO observation categories. These free flyers are conceived to be sophisticated satellites capable of long term untended operation in highly inclined low earth orbits and requiring, perhaps, a few shuttle flights for unscheduled maintenance or replacement. The increment in Program costs for this option is significant.

Intermediate inclinations (55 deg) offer the opportunity to perform the STO mission with reasonable results from the SCB for a modest increase in transportation costs.

The 85 deg inclined orbit option is Program Option 3 in Grumman's Space Station Systems Analysis Study.

G419T

LEO INCLINATION OPTIONS

EVAL. STO PERFORMANCE AGAINST INCLNTN COSTS

ORBIT INCLN	28½°	45°	55°	≏ 85°
STO OBSV CAT				
SOLAR	ON SCB			
TERRES		ON SCB	ON SCB	ON SCB
ATMOS	ON FREE FLYER			
MAGNET		?		
Δ COST 84-91 INCL, ($M)				
FREE FLYER	?			
TRANSPORT		250	500	
Δ SCB PRG COST				1080

GRUMMAN

G-419

FLIGHT CONTROL SUBSYSTEM

During Part 2 of the study, preliminary design of the Space Station Flight Control Subsystem was initiated. Requirements were formulated and analyses were conducted in order to arrive at a design approach. This led to a tentative selection of hardware components which formed the basis of preliminary subsystem performance, weight, power and cost estimates.

FLIGHT CONTROL SUBSYSTEM

- REQUIREMENTS
  - FUNCTIONS
  - PROBLEM STATEMENT
  - DESIGN GOALS
- CONCEPT ANALYSIS
  - LEO AXIS ORIENTATION
  - VEH DESIGN MODS/IMPROVED FLT CONTROL
  - GRAV GRAD TORQUE PROFILE
  - STABILIZATION TORQUE ESTIMATES
  - STAB AND CONTROL PERFORMANCE
  - FLEXIBLE MODE STABILIZATION
  - SLEW MANEUVER PERFORMANCE
- HARDWARE PRELIMINARY DESIGN
  - HARDWARE SELECTION
  - HARDWARE CHARACTERISTICS
  - RCS PROPELLANT REQUIREMENTS
  - SUBSYSTEM BLOCK DIAGRAM
  - COMMONALITY MATRIX
  - BACKUP PROVISIONS
- SUBSYSTEM FEATURES
- CONCLUSIONS AND NEXT STEPS

GRUMMAN

F-373

SPACE FLIGHT CONTROL FUNCTIONS

Five functions to be performed by the Flight Control Subsystem are identified. The Attitude Stabilization and Control function drives the subsystem configuration. For this reason, most of the Part 2 flight control effort has been devoted to stabilization and control. LEO Altitude Maintenance is discussed elsewhere under the briefing topic, CONCEPT DEVELOPMENT. Station Slewing has been briefly treated. Geostationary Orbit Stationkeeping and Solar Array Pointing functions will be considered during Part 3.

F-307T

SPACE STATION FLIGHT CONTROL FUNCTIONS

MULTI-FUNCTIONED SUBSYSTEM

- ATTITUDE STABILIZATION AND CONTROL
- LOW EARTH ORBIT ALTITUDE MAINTENANCE
- GEOSTATIONARY ORBIT STATIONKEEPING (PART 3 TASK)
- STATION SLEWING
- SOLAR ARRAY POINTING

GRUMMAN

F-307

SPACE STATION ATTITUDE STABILIZATION AND CONTROL

PROBLEM STATEMENT

The Stabilization and Control functions include aligning the Space Construction Base and the Solar Array to different targets in space and then stabilizing the base and array motion.

For Space Station operations, a number of problems arise in performing these functions. One major problem which constitutes a new challenge in manned flight control are the very large changes in configuration and inertia which occurs over the long period of Space Station operations for each Program Option. Another significant challenge is to stabilize a vehicle, a large part of which possesses structural bending and torsion modes.

SPACE STATION ATTITUDE STABILIZATION & CONTROL

PROBLEM STATEMENT

FLEXIBILITY AND INERTIA CHANGES: NEW CHALLENGES

STABILIZATION & CONTROL FUNCTIONS

- BASE AND SOLAR ARRAY POINTING
- BASE AND ARRAY STABILIZATION

FUNCTIONS PERFORMED WITHIN SPEC LIMITS DESPITE:

- LARGE INERTIA CHANGES DUE TO:
  - CONST OF SOLAR ARRAYS AND ANTENNAS
  - STA CONFIGS (E.G., CONST BASE, ORB DEPOT, DOCKED STS)
  - REMOTE MANIP, TELEOPER, CREW MOTION
- FLEXIBILITY OF LARGE STRUCTURES
- CONFLICTING ELEMENT POINTING REQMTS
- NATURAL TORQUES
  - GRAVITY GRADIENT
  - AERODYNAMIC DRAG
  - SOLAR PRESSURE
  - MAGNETIC FIELD

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FLIGHT CONTROL SUBSYSTEM DESIGN GOALS

To date, four major design goals have been surfaced.

In view of the long duration for Space Station operations, the necessity to conserve expendables is apparent. This is particularly true for RCS propellants in view of the ground-to-orbit transportation cost as well as the onboard storage requirements. As will be developed, passive stabilization has been considered, using gravity gradient as a restoring torque.

Another important goal is to provide a means, via the flight control subsystem, to limit the local accelerations which the structure will experience. This goal is related to preserving the integrity of large flexible structures which will be constructed and assembled in space.

Other goals cover the application of the same concepts and hardware for all vehicle configurations, orbital regimes and flight control functions.

The term "Flexible Flier" control characterizes the kind of flight control which is sought for Space Station operations. Subsystem flexibility, in this sense, means:

- Adaptable to large configuration/inertia changes
- Capable of stabilizing elastic structure modes
- Contains hardware elements which serve many functions.

FLIGHT CONTROL SUBSYSTEM DESIGN GOALS

"FLEXIBLE FLIER" CONTROL REQUIRED

- MIN PROPELLANT AND POWER UTILIZATION
- LIMITED FLT ACCELERATIONS TO ASSURE STRUCT INTEGRITY
- SAME CONTROL CONCEPT FOR ALL
  - SPACE STATION CONFIGS
  - LEO AND GSO OPS
- COMMON HARDWARE USAGE FOR ALL FLT CONTROL FUNCTIONS

GRUMMAN

F-309

ADVANCE CONSTRUCTION BASE — IDENTIFICATION OF AXES

Shown here schematically is the Advance Construction Base configuration of the Space Station. The base itself consists of:

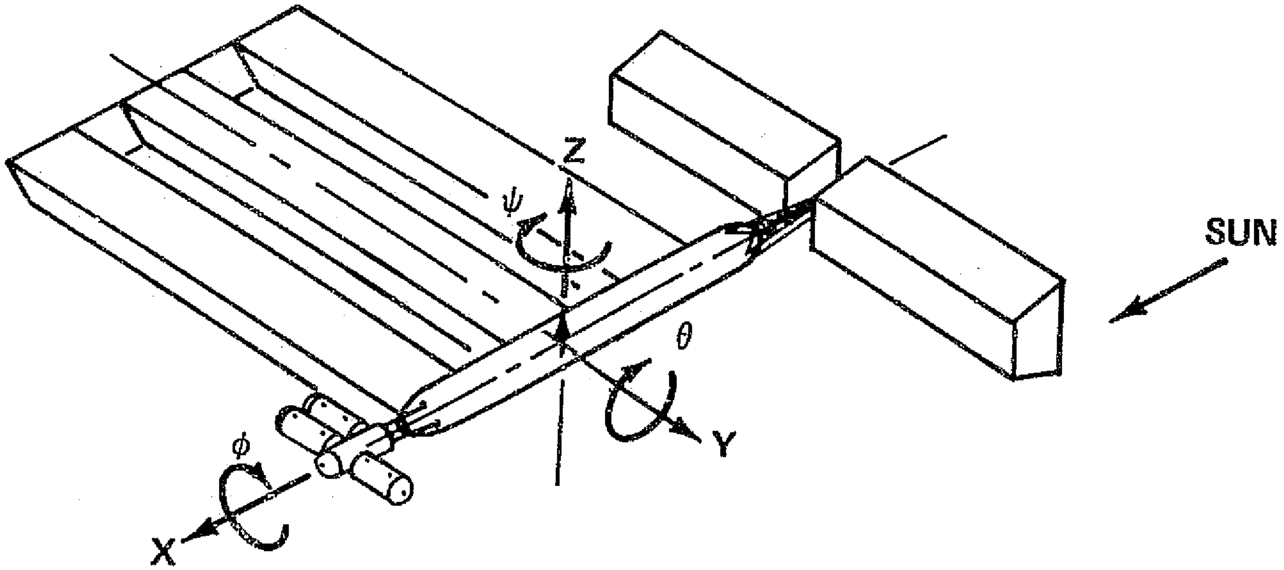
- Two expended STS tanks attached end to end to form the base spine
- A set of modules to provide crew habitation, subsystem support, manufacturing development, logistics, etc.
- A rotatable solar array to collect electric energy for the base's operations

Included on the base (but not shown) are the beam fabrication machines and the Remote Manipulator/Crane which moves hardware around the base.

An orthogonal set of vehicle axes are identified and the corresponding angular motions are defined for reference in the subsequent discussion.

Finally, a large 2 mw, 3-section Solar Power Development Article is shown extending in the -Y direction from the base spine.

ADVANCED CONSTRUCTION BASE
IDENTIFICATION OF AXES



F-303

PREFERRED AXIS ORIENTATION SELECTION CRITERIA

LOW EARTH ORBIT OPERATIONS

In order to reduce RCS propellant consumption, as would be required for active stabilization, the concept has been advanced to utilize gravity gradient as a control rather than a disturbance torque. If control about each axis is considered a second order system with the classical inertia, damping and spring terms, gravity gradient could supply the spring term as a restoring torque about two axes provided that the minimum moment of inertia axis is directed at the geocenter. Damping must be provided by active torquing. Such quasi-passive stabilization is feasible if precise control is not a mission requirement. Space Station mission performance permits slow, large angle (±5°) limit cycle motion during a major part of orbital operations. Moreover, pointing the minimum inertia axis at the geocenter does not appear to conflict with mission requirements.

Since control about the minimum inertia axis does not benefit from the gravity gradient, the selection of which of the other two axes should be aligned with the flight direction is based on which would yield the lower aerodynamic drag disturbance torque. This torque must, in general, be counted by an active control torque.

An additional criterion for preferred axis orientation is alignment of the vehicle axis with least frontal area to the flight direction. This alignment reduces the fuel needed by the RCS for periodic thrust to overcome drag and maintain LEO altitude.

PREFERRED AXIS ORIENTATION SELECTION CRITERIA
LOW EARTH ORBIT OPERATIONS

DESIGN FOR MIN ENERGY CONSUMPTION

FUNCTION	CRITERION	AXIS ORIENTATION
STABILIZATION & CONTROL	APPLY GRAVITY GRADIENT TO MINIMIZE RCS PROP CONSUMP	• MIN MOMENT OF INERTIA AXIS POINTS TO GEO CENTER • ALIGN ONE OF OTHER TWO AXES WITH LESSER DRAG TORQUE TO FLIGHT DIRECTION
ALTITUDE MAINTENANCE	MINIMUM RCS PROP CONSUMPTION	• ALIGN AXIS WITH LOWEST FRONTAL AREA TO FLIGHT DIRECTION

GRUMMAN

F-310

SELECTION OF LEO PREFERRED AXIS ORIENTATION

With the axis orientation selection criteria defined, all six possible orientations were considered for the Advanced Construction Base configuration before and after the 2 mw large SPDA solar array structure has been constructed.

For each configuration, the impact of axis orientation on RCS propellant consumption is qualitatively assessed. For example, for the configuration prior to array construction, X-axis pointing to the geocenter permits gravity gradient to assist in stabilization. Conversely, Y- and Z- axis earth pointing will cause larger amounts of RCS fuel to be consumed. With the X-axis directed to the geocenter, the choice is made of aligning the Y-axis to the flight direction rather than the Z-axis. This choice is dictated again by propellant consumption considerations since less drag and drag torque are experienced. Thus, as noted, the minimum fuel consumption orientation of vehicle axes during most orbital operations corresponds to:

- X - geocenter
- Y - flight direction
- Z - perpendicular to orbit plane

Similar reasoning for the configuration after the large SPDA array has been constructed leads to this choice of axes orientation:

- X - flight direction
- Y - geocenter
- Z - perpendicular to orbit plane

SELECTION OF LEO PREFERRED AXES ORIENTATION

CLEAR OPTIMUM APPARENT

SOLAR ARRAY CONFIGURATION	AXIS ORIENTATION			PROP CONSUMP FOR ALT MAIN & STAB & CONTROL
	EARTH POINTING	FLIGHT DIRECTION	PERP TO ORB PLANE	
BEFORE CONSTRUCTION	X	Y	Z	MINIMUM √
	X	Z	Y	HIGHER
	Y	X	Z	HIGHER
	Y	Z	X	VERY HIGH
	Z	X	Y	VERY HIGH
	Z	Y	X	HIGHER
AFTER CONSTRUCTION	X	Y	Z	HIGHER
	X	Z	Y	VERY HIGH
	Y	X	Z	MINIMUM √
	Y	Z	X	VERY HIGH
	Z	X	Y	HIGHER
	Z	Y	X	HIGHER

GRUMMAN

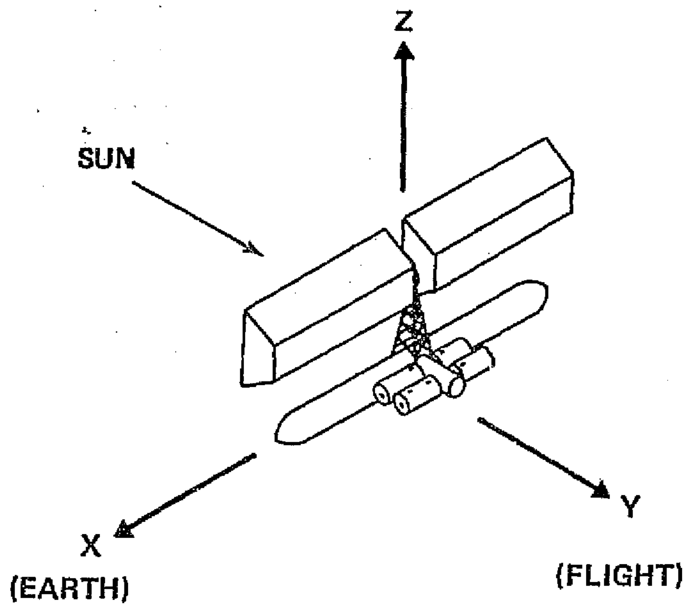
F-311

VEHICLE DESIGN MODS FOR IMPROVED FLIGHT CONTROL – SPACE CONSTRUCTION BASE

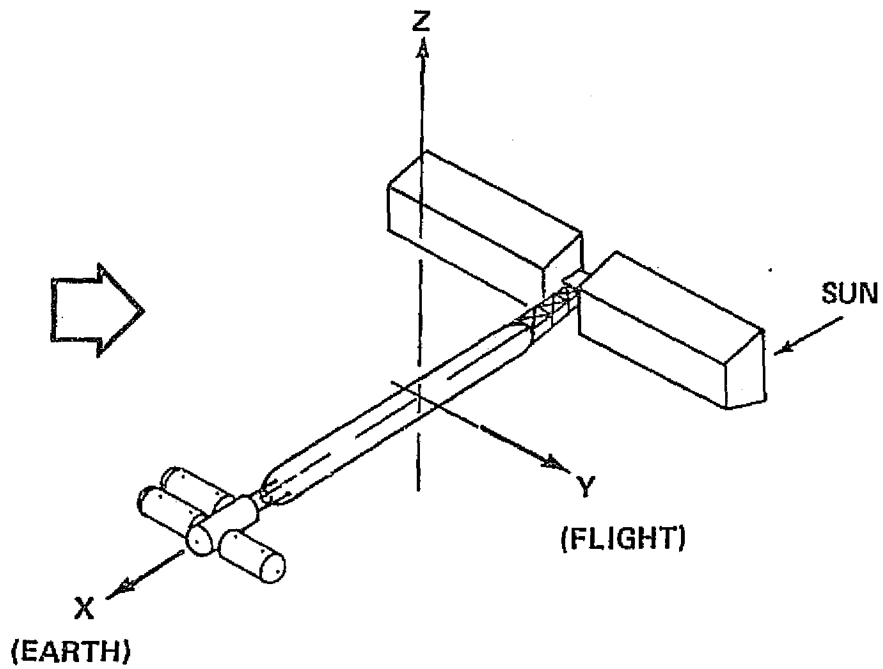
Two modifications were made to the 30 November, 1976 Space Construction Base configuration. The base solar array was relocated from atop the Z-axis post to an aft location on the base spine (X-axis). The modules for habitation, subsystems, etc. which were placed amidship previously are relocated to a forward position on the base spine (X-axis). Both of these modifications halved the X-axis moment of inertia and increased the Y- and Z-axes moments of inertia by a factor of 3.8. Taken together, these moment of inertia changes increase the difference between the Z- and Y-axis inertias and between the Y- and X-axis inertias by a factor of 6.5. The net effect increased the gravity gradient stabilizing torque by a factor of approximately 5.2. This contributes materially to the concept of passive stabilization.

VEHICLE DESIGN MODS FOR IMPROVED FLIGHT CONTROL
SPACE CONSTRUCTION BASE

NOV 30 CONFIG



PRESENT CONFIG



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MOD

- MOMENT OF INERTIA DIFFERENCES ($I_Z - I_X$) AND $I_Y - I_X$) INCREASED BY FACTOR OF 6.5

EFFECT

- GRAVITY GRADIENT STAB TORQUE INCREASED BY FACTOR OF APPROX 5.2

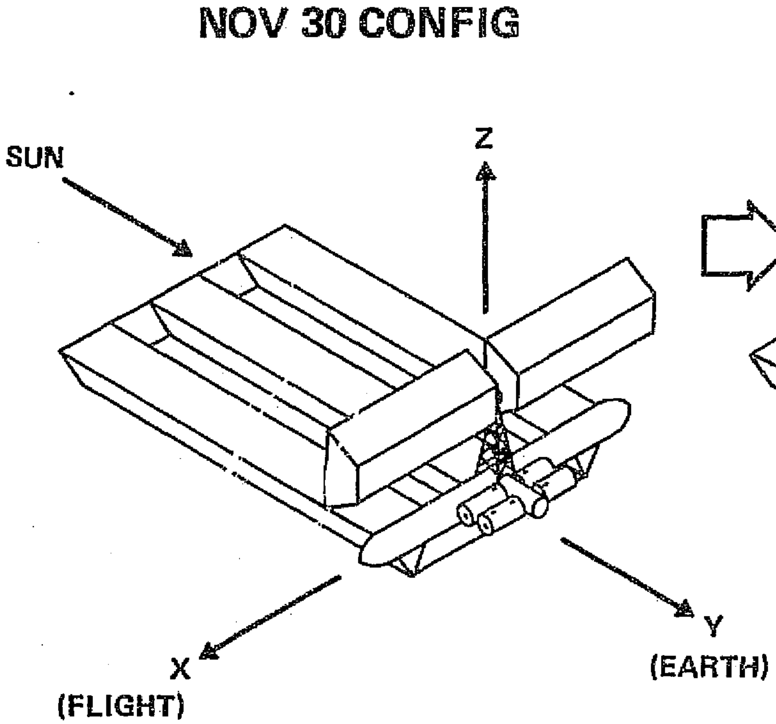
GRUMMAN

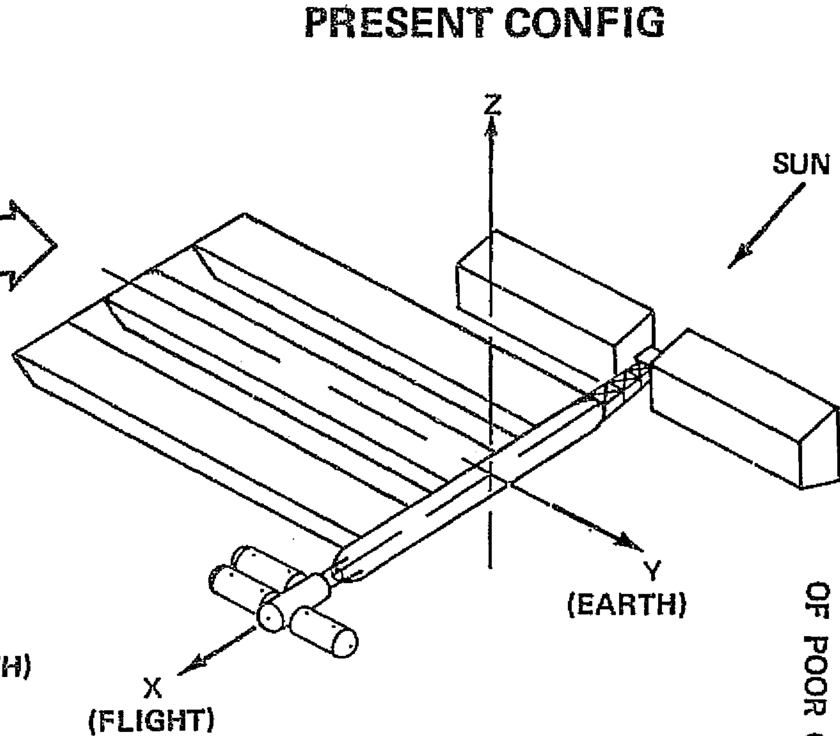
VEHICLE DESIGN MODS FOR IMPROVED FLIGHT CONTROL SPACE CONSTRUCTION BASE WITH 2 MW SPDA

For the Space Construction Base configured with the constructed 2 mw Solar Power Development Article, the relocation of the rotatable base solar array as indicated creates a stabilizing torque about the Y-axis. Such a torque originates from the array drag which acts through a center of pressure that is behind the vehicle center of gravity. Thus, a restoring torque (-0.4 nm/deg), analogous to a weathercock stabilizing torque, is developed. Such a restoring torque contributes to stabilization in a passive sense since, without it, RCS propellant would be expanded to control about the Y-axis which receives no gravity gradient torque. ives no gravity gradient torque.

F-363T

VEHICLE DESIGN MODS FOR IMPROVED FLIGHT CONTROL
SPACE CONSTRUCTION BASE WITH 2MW SPDA





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MOD	EFFECT
SOLAR ARRAY MOVED TO LOCATION ON X-AXIS AFT OF VEHICLE CG DRAG FORCE ACTS THRU CP AFT OF CG	WEATHERCOCK STAB TORQUE (-0.4 NM/DEG) CREATED ABOUT Y AXIS WHICH HAS NO GRAV GRADIENT RESTORING TORQUE

GRUMMAN

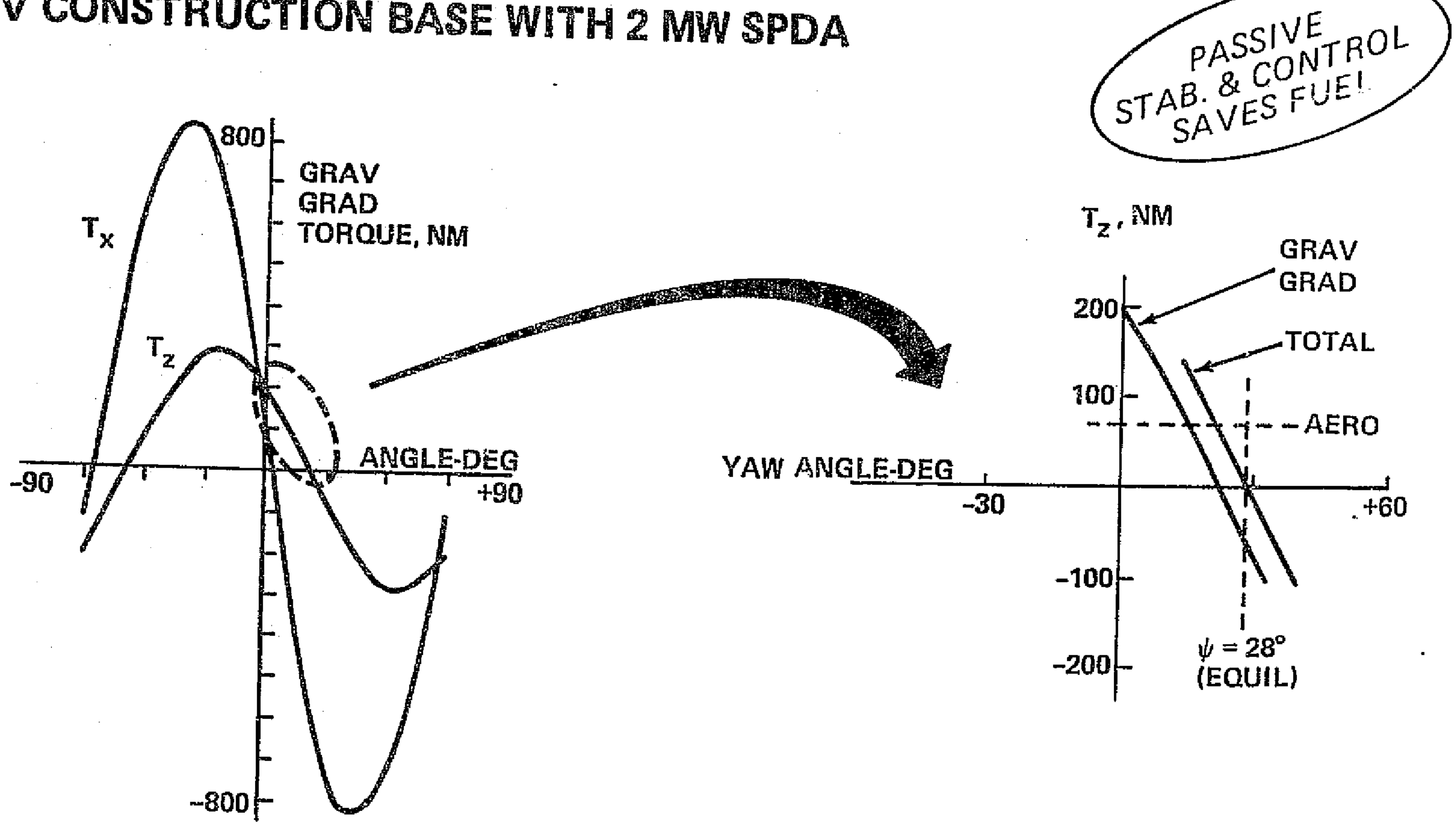
GRAVITY GRADIENT AS A STABILIZING TORQUE

On the left side, the results of a gravity gradient torque survey are presented for the Advance Construction Base configuration with the 2 mw Solar Power Development Article attached. X- and Z-axis torque profiles over a 180 deg angular range are shown to be approximate sine functions. The angle at which each curve crosses the zero torque axis (near the zero angle point) corresponds to the misalignment between principal and vehicle geometric axes. This angular difference is attributable to the existence of cross products of inertia. The local slope of both torque plots in the ± 30 deg range is both linear and negative. This indicates the gravity gradient provides a restoring torque which can contribute to passive stabilization.

On the right side, the section of the T_Z (due to gravity gradient) versus angle curve has been expanded in the angular range from 0 to 30 deg. Added to this plot is the aerodynamics torque which must be countered by the gravity gradient torque. As shown, at a yaw angle of 28 deg, these torques are equal in magnitude and opposite in sign. Thus, the vehicle will tend to maintain an equilibrium condition at this angle. The limit cycle oscillation about the equilibrium position will be suppressed in accordance with the damping that is supplied as part of the control loop.

F306T

GRAVITY GRADIENT AS A STABILIZING TORQUE
ADV CONSTRUCTION BASE WITH 2 MW SPDA



- GRAV GRAD PROVIDES RESTORING TORQUE THAT OFFSETS AERO AND OTHER DISTURBANCE TORQUES
- STABILIZATION OBTAINED WITHOUT EXPENDITURE OF RCS PROPELLANT

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GRUMMAN

F-306

STABILIZATION TORQUE ESTIMATES

For the Advanced Construction Base configuration, both the gravity gradient and aerodynamic torques have been estimated. The resulting data which are presented have been used to estimate stabilization and control loop performance.

F-312T

STABILIZATION TORQUE ESTIMATES

GRAV GRAD STABILIZES DRAG TORQUE

TORQUE ORIGIN	ADVANCED CONST BASE CONFIG					
	BEFORE			AFTER		
	T_x	T_y	T_z	T_x	T_y	T_z
GRAVITY GRADIENT, NEWTON-METERS/DEG	0	-20	-20	-27	0	-10
AERO DRAG, NEWTON-METERS	0.3	–	5	–	6	59

NOTES: (1) 400 KM/28.5° ORBIT
(2) SPATIAL ORIENT. VEH AXES AS SHOWN IN ACCOMP DIAGRAMS

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F-312

STABILIZATION AND CONTROL PERFORMANCE ADVANCED CONSTRUCTION BASE BEFORE CONSTRUCTION

With the axes orientation that has been selected, as discussed previously, it is estimated that the effect of gravity gradient stabilization about the Z-axis is to save about 500 lb of RCS propellant in a 90-day mission period. This estimate assumes RCS thrusters which have an I_{sp} of 235 sec and a moment arm of 68 m.

For motion about the X-axis, for which no gravity gradient stabilization occurs, an expenditure of 100 lb, of RCS fuel is required over a 90-day period. In this case the thruster moment arm is 22 m.

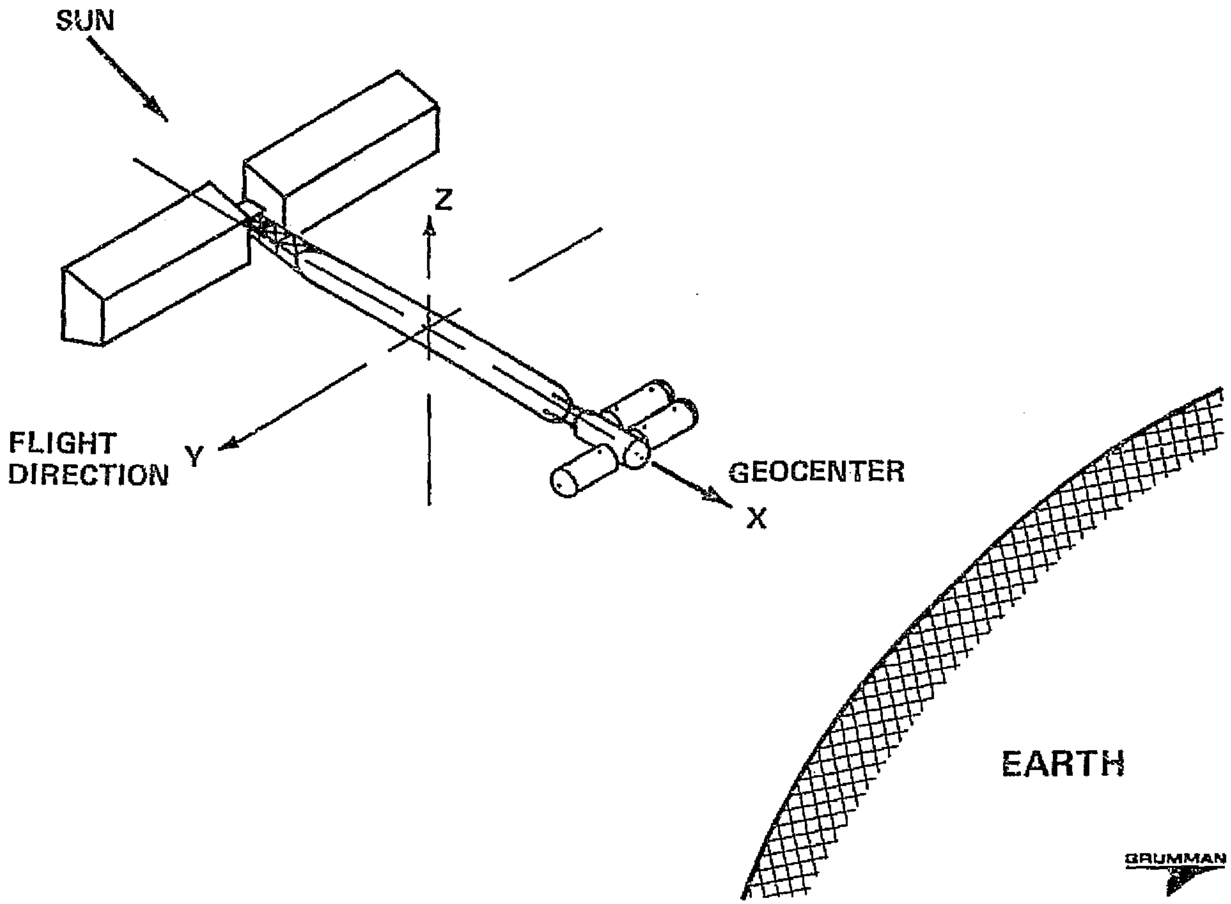
STABILIZATION & CONTROL PERFORMANCE

ADVANCED CONSTR BASE CONFIGURATION

BEFORE CONSTRUCTION

$I_{XX} = 19 \times 10^6$ KG - M^2
$I_{YY} = 334 \times 10^6$ KG - M^2
$I_{ZZ} = 336 \times 10^6$ KG - M^2

- ORIENT OF AXES PERMITS GRAV GRAD TORQUE TO OVERCOME LOW AERO DRAG TORQUE ABOUT Z-AXIS
- APPROX 500 LB OF RCS FUEL SAVED FOR 90 DAY MISSION
- APPROX 100 LB OF RCS FUEL REQD FOR X-AXIS CONTROL FOR 90 DAY MISSION



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F-302

STABILIZATION AND CONTROL PERFORMANCE ADVANCED CONSTRUCTION BASE AFTER CONSTRUCTION

For this configuration with the vehicle axes as selected, gravity gradient stabilization about the Z-axis saves about 6000 lb of RCS fuel.

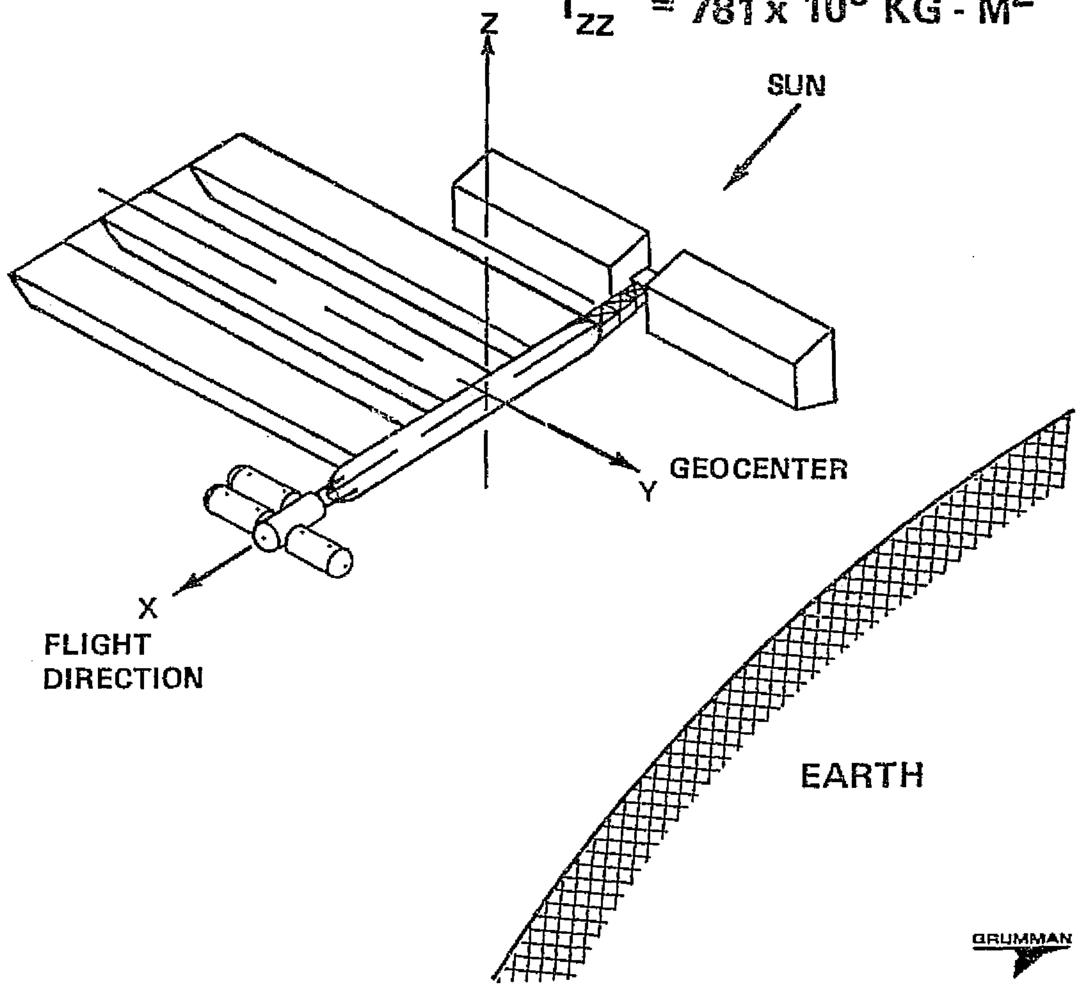
Motion about the Y-axis is not restored by gravity gradient torques. However, when such motion is stabilized by the drag acting on the base Solar Array, approximately 600 lb, of RCS fuel is saved. The thruster moment arm is 68 m.

F-301T

STABILIZATION & CONTROL PERFORMANCE
ADVANCED CONSTR BASE CONFIGURATION
AFTER CONSTRUCTION

$I_{XX} = 454 \times 10^6$ KG - M^2
$I_{YY} = 346 \times 10^6$ KG - M^2
$I_{ZZ} = 781 \times 10^6$ KG - M^2

- GRAVITY GRAD TORQUE OVERCOMES Z-AXIS AERO DRAG TORQUE
- APPROX 6K LB OF RCS FUEL SAVED FOR 90 DAY MISSION
- BASE SOLAR ARRAY PROVIDES Y-AXIS WEATHERCOCK STABILIZATION
- APPROX 600 LB OF RCS FUEL SAVED FOR 90 DAY MISSION



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PREFERRED CONSTRUCTION BASE ORIENTATION SUMMARY

Based on the previously described stabilization performance results, the preferred orientation of the vehicle X, Y and Z-axes are summarized. These orientations are recommended for major portions of the Space Station mission during which:

- Coarse limit cycle motion is permitted
- Mission requirements do not dictate other preferred vehicle orientations.

F-361T

PREFERRED CONSTRUCTION BASE ORIENTATION SUMMARY

CONFIGURATION	AXIS		
	X (ROLL)	Y (PITCH)	Z (YAW)
BEFORE SOLAR ARRAY CONSTRUCTION	EARTH POINTING	VEL VECTOR ALIGNED	PERP TO ORBIT PLANE
AFTER SOLAR ARRAY CONSTRUCTION	VEL VECTOR ALIGNED	EARTH POINTING	PERP TO ORBIT PLANE

GRUMMAN

F-361

FLEXIBLE MODE STABILIZATION

The presence of large elastic structures which are fabricated by the Space Construction Base will influence vehicle stabilization. Based on previous Grumman experience, it is planned to stabilize the flexible structure bending and torsion modes together with the rigid body motion. Two techniques are considered in this connection.

The simplest approach is to model the flexible body motion and gain schedule the control loop parameters as the elastic structure grows. This represents an "open loop" accounting of the elastic motion. If this technique does not satisfactorily stabilize the vehicle and limit critical structural inertia loads, then a more sophisticated control technique is planned. This technique is termed "adaptive" in that bending/torsion modes are sampled at 10 sec intervals from on-board accelerometer and strain gage sensors. The measured data are then used as inputs to a Kalman filter to shape the control loop parameters. The number and location of these sensors would be determined by dynamic analysis as part of the control subsystem software design. This adaptive technique can be implemented in a manner which preserves the integrity of the structure while it is growing in orbit.

F376T

FLEXIBLE MODE STABILIZATION

- ELASTIC STRUCTURE MOTION STABILIZED IN CONJUNCTION WITH RIGID BODY STABILIZATION

- ELASTIC STRUCTURE STATE DETERMINED BY KALMAN FILTER
  - SAMPLED DATA TECHNIQUE (10 SEC/SAMPLE)
  - BENDING/TORSION MOTION SENSOR MEASUREMENTS

- LIMITED NUMBER OF ACCEL/STRAIN GAGE SENSORS AT LOCATIONS PRE-DETERMINED BY ANALYSIS

- GAIN SCHEDULING ACCOUNTS FOR CONFIG/LARGE INERTIA CHANGES

GRUMMAN

F-376

SIMULATION RESULTS OF FLEX MODE STABILIZATION

Grumman has developed a combined rigid/flexible body dynamic model for the adaptive control technique. The model has been programmed for digital simulation. The dynamic properties of the Advanced Construction Base configuration with the 2 mw Solar Power Development Article attached were evaluated. Results are shown for roll motion about the X-axis with the first three bending modes included. Roll rate as a function of time is presented. Two effects may be noted. The oscillation having a period of about 60 sec corresponds to the 0.1 rad/sec first bending mode. The longer period oscillation (about 600 sec) represents the second mode (0.01 rad/sec). Both of these oscillations are damped indicating the ability of the control algorithm to stabilize the roll motion.

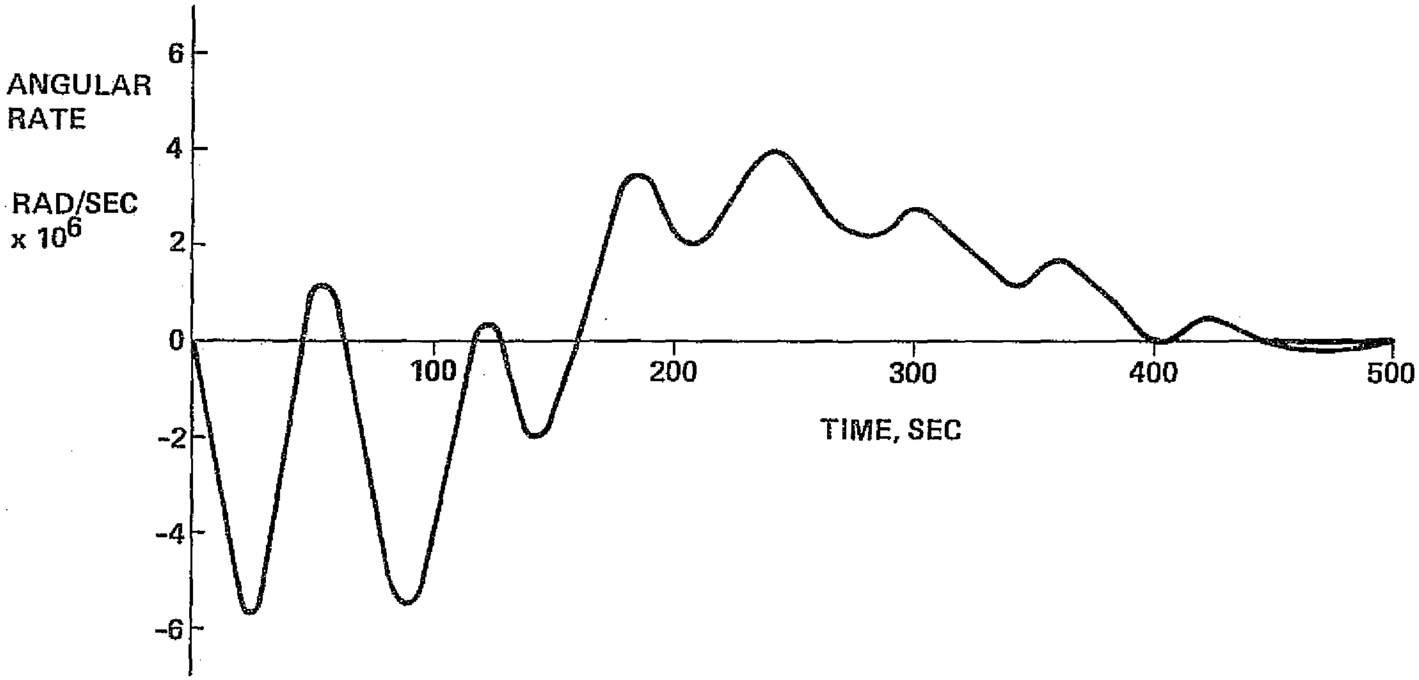
F375T

SIMULATION RESULTS OF FLEX MODE STABILIZATION

ASSUMPTIONS

- ADV CONST BASE WITH 2 MW SPDA
- X-AXIS MOTION ONLY ($I_{xx} = 4.5 \times 10^8$ KG-M^2)
- THREE BENDING MODES (0.1, 0.01 AND 0.001 RAD/SEC)
- NO STRUCTURAL DAMPING

MOTION WITH SUPPRESSED BENDING MODES



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F-375

SLEW MANEUVER

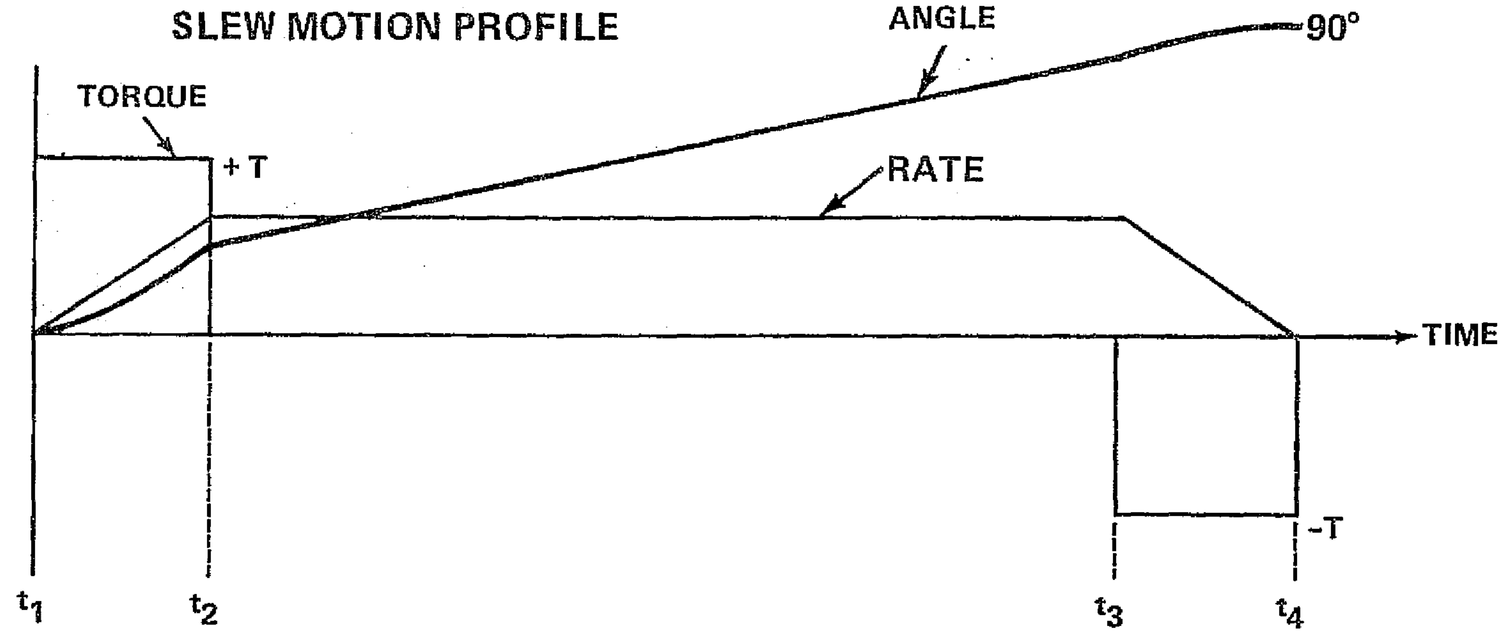
At special times during the life of the Space Station, it may be necessary to undertake large angle slew maneuvers. Reasons for reorienting the vehicle include:

- Testing a large solar array that had been constructed in orbit
- Testing a large PSP antenna that had been assembled in orbit.

The control technique to perform slew maneuvers is the torque the vehicle for a fixed time, remove the torque so as to permit the vehicle to coast and then apply the same torque magnitude but in the opposite direction for the same time as initially applied. This procedure would be monitored by the Attitude Reference Unit in response to Flight Control Computer commands. Two natural boundaries exist for the impulse level which is applied. For minimum RCS fuel consumption, a minimal impulse is used and the vehicle is allowed to coast for a long period of time. The other extreme is to apply a high level of impulse until one half of the desired slew angle is attained and then reverse the direction of impulse for an equal time until the final angle is reached. This latter approach yields minimum time slews.

F313T

SLEW MANEUVER



BOUNDARIES:

- **MINIMUM FUEL** CONSUMP WHEN BASE IS ACCEL FOR MIN THRUST-ON TIME, COASTS FOR MAX PERIOD, DECEL FOR MIN THRUST-ON TIME
- **MINIMUM TIME** TO SLEW 90° WHEN BASE IS ACCEL FOR ONE-HALF TOTAL PERIOD, THEN DECEL FOR REMAINING HALF PERIOD

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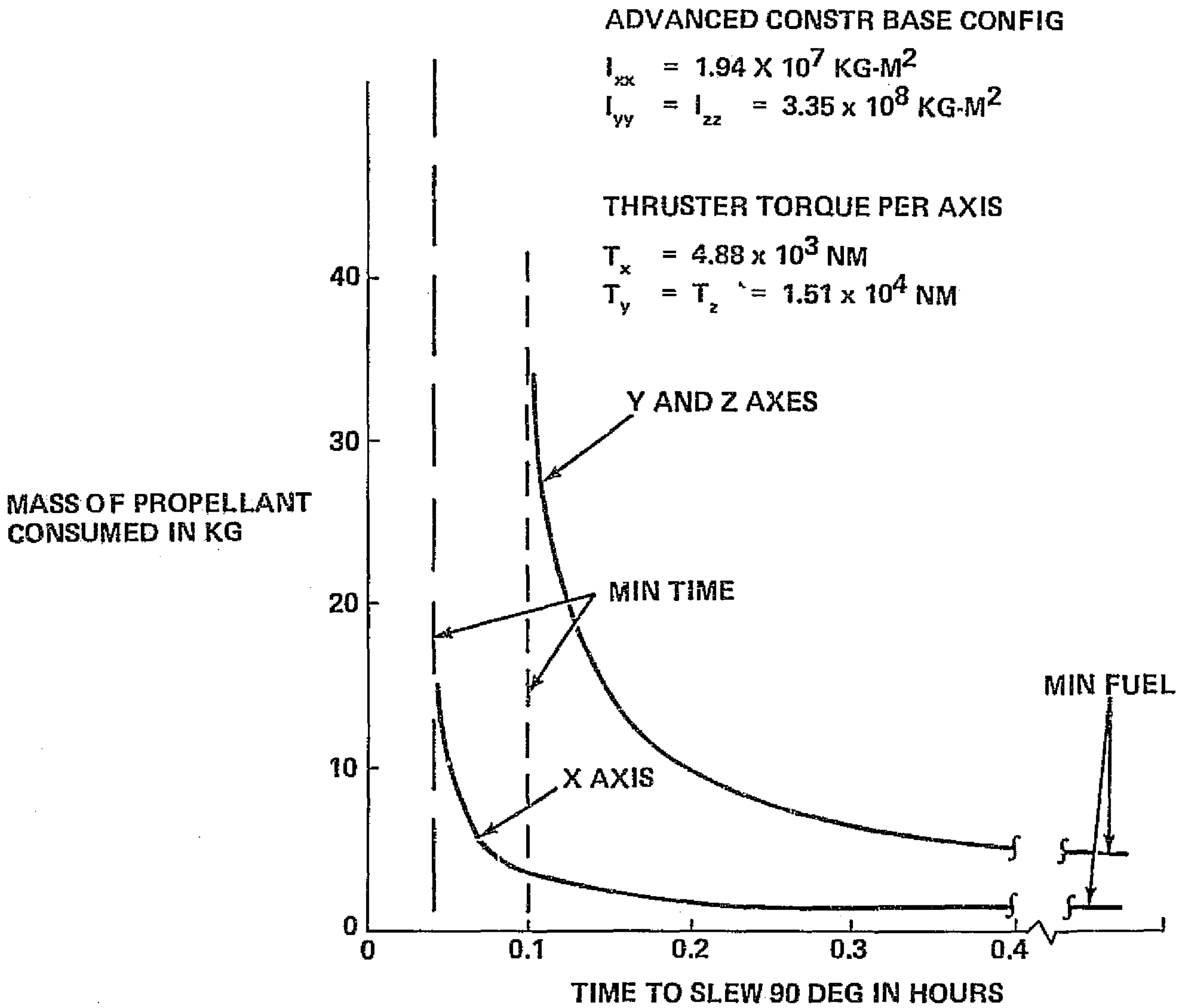
F-313

SPACE STATION RCS PROPELLANT CONSUMPTION 90 DEG SLEW MANEUVERS

The amount of RCS propellant used to perform 90 deg slew maneuvers about each of the three vehicle axes has been estimated as a function of time to slew. An Advanced Construction Base configuration has been assumed with thrusters capable of delivering 220 N thrust and 235 sec specific impulse. The minimum time and minimum fuel boundaries are indicated.

F-314T

SPACE STATION RCS PROPELLANT CONSUMPTION
90 DEG SLEW MANEUVERS



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F-314

FLIGHT CONTROL HARDWARE SELECTION CRITERIA

In order to size and cost the various Space Station Program Options, a preliminary selection has been made of the Flight Control Subsystem hardware. This early selection is based on the concept analysis results which have been described and the criteria which are noted. The criteria are not cited in order of importance.

F-321T

FLIGHT CONTROL HARDWARE SELECTION CRITERIA

- TECHNICAL PERFORMANCE
- LOW COST
- SPACE FLIGHT PROVEN
- COMMONALITY:
  - SERVES MORE THAN ONE FLIGHT CONTROL FUNCTION
- REDUNDANT PATH PROVIDED
- ONBOARD MAINTAINABLE

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F-321

PRELIMINARY HARDWARE SELECTION

These hardware items have been tentatively selected pending additional performance analysis. The accelerometer and strain gage sensors are not critical in terms of weight and cost. These will be chosen following additional flexible structure studies.

F-320T

PRELIMINARY HARDWARE SELECTION

ITEM	MANUFACTURER	MODEL/TYPE
SENSORS		
• EARTH HORIZON	TRW	EARTH DISC SCAN
• SUN	ADCOLE	16764/TWO AXIS DIGITAL
• MAGNETOMETER	SCHONSTEDT	SAM-63C-1
• ATTITUDE REFERENCE	KEARFOTT	ANALOG REBALANCE
• ACCELEROMETERS	TBD	—
• STRAIN GAGES	TBD	—
COMPUTER	IBM	AP — 101
THRUSTERS/TORQUERS		
• RCS	TRW	MRE - 50A
• CMG'S	BENDIX	MA-2300
• MAGNETIC COILS	BOEING	150 POLE-CM

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PRELIMINARY HARDWARE CHARACTERISTICS SUMMARY

Performance and physical characteristics are listed for most of the hardware items identified on the previous page. The RCS characteristics are presented on the next page.

Selection of CMG's will be reviewed in the light of 3-axis dynamic simulation results. It may be possible to substitute lower cost reaction wheels or plasma thrusters for the CMG's if the requirements for such devices can be limited to developing loop damping torque.

F-367T

PRELIMINARY HARDWARE CHARACTERISTICS SUMMARY

ITEM	PERFORMANCE	SIZE (IN)	POWER (W)	WEIGHT (LB)
EARTH HOR SENSOR	± 0.05 DEG	5 X 7 X 10 (HEAD)	10.5	10
SUN SENSOR	0.25 DEG (ACC) 0.5 DEG (RES)	3 X 3 X 1 4 X 4 X 1	12 VDC 8 MA	1.2
MAGNETO-METER	± 1% OF READING	5 X 3 X 3	1.1	3
ATT REF UNIT	± 0.3 DEG/HR/3 HR 1 DEG/SEC (RATE)	11 X 7 X 3	40 (MAX) 15 (STEADY)	6
COMPUTER (2)	32K MAX MEM 16 BIT WORD	1500 IN^3	330	45
CMG'S (2)	2300 FT/LB/SEC @ 9000 RPM	41 IN DIA SPHERE	300 (MAX) 150 (STEADY)	418
MAGNETIC COILS (3)	150K POLE-CM	32 X 1D	4 (PEAK) 1 (AVE)	5

NOTE: SIZE, POWER AND WEIGHT ARE FOR ONE UNIT

F-367

RCS SUBSYSTEM CHARACTERISTICS

One set of reaction control clusters have been selected to satisfy the needs of several functions:

- Altitude maintenance
- Slew maneuvering
- Stabilization and control.

Each cluster has a redundant thruster in each axis. This means that, barring thruster failures, each control axis has a double torque emergency capability.

Each cluster is a self contained, unit; it contains, besides the thrusters, the propellant feed and pressurization systems to support the required thruster firings.

F364T

RCS SUBSYSTEM CHARACTERISTICS

THRUSTERS

• TYPE	MONOPROPELLANT HYDRAZINE
• THRUST/THRUSTER	220 N (50 LBF)
• NO. THRUSTERS PER CLUSTER	8
• CLUSTERS/SUBSYSTEM	4
• Isp (STEADY STATE)	230 SEC
• INLET PRESS.	300 PSIA
• MFG/MODEL	TRW/MRE-50A
• PROGRAM	MARINER MARS 1971

PROPELLANT FEED SYSTEM

• PROP. TYPE	HYDRAZINE
• USABLE PROP. WT	300 KG
• TANK DIA (BLADDERED)	0.86 M
• FEED SYS WT (DRY)	21 KG

PRESSURIZATION SYSTEM

• PRESURANT/WT	He/2.3 KG
• STORAGE PRESS.	4500 PSIA
• TANK WT	26 KG
• PLUMBING WT	2.3 KG

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RCS PROPELLANT REQUIREMENTS – OPTION 2B – SHEET 1 OF 2

RCS propellant requirements in LEO for Option 2B are summarized by quarter of each year from 1984 through 1988. These data have been used in the integrated requirements estimates as well as the transportation requirement study task.

F-365T

RCS PROPELLANT REQUIREMENTS
OPTION 2B – SHEET 1 OF 2

	84				85				86				87				88			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
• ALTITUDE KEEPING																				
– DRAG (N)		0.218	0.218	0.225	0.118	→	→	→	0.206	0.499	0.224	0.224	0.321	→	→	→	0.515	0.447	0.447	0.515
– $I_{TOT} \times 10^{-6}$ (N – SEC)		1.72	1.72	1.77	0.93	→	→	→	1.62	3.93	1.77	1.77	2.53	→	→	→	4.06	3.52	3.52	4.06
– PROP. REQMT (KG)(1)		761	761	886	420	→	→	→	716	1741	777	777	1120	→	→	→	1805	1554	1554	1805
• SLEWING PROP. (KG)(2)		30	→	→	30	→	→	→	30	→	→	→	30	→	→	→	30	→	→	→
• ATTITUDE STAB. & CONTROL PROP. (KG)		57	→	→	57	→	→	→	57	372	57	57	57	→	→	→	57	→	→	→
TOTAL PROPELLANT (KG)		848	848	973	507	→	→	→	803	2193	864	864	1207	1207	1207	1207	1892	1641	1641	1805

(1) ASSUMES I_{SP} = 230 SEC STEADY STATE

(2) ONE 90 DEG SLEW/AXIS PER QTR

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F-365 (SPS-T 138)

RCS PROPELLANT REQUIREMENTS – OPTION 2B – SHEET 2 OF 2

The RCS fuel requirements shown on Sheet 1 have been extended on Sheet 2 to cover the years from 1989 to 1994.

F-366T

RCS PROPELLANT REQUIREMENTS
OPTION 2B – SHEET 2 OF 2

	89 /QTR	90 /QTR	91 /QTR	92 /QTR	93 /QTR	94 /QTR
• ALTITUDE KEEPING						
– DRAG (N)	0.537	0.620	0.675	0.652	0.574	0.491
– $I_{TOT} \times 10^{-6}$ (N – SEC)	1.47	4.88	5.32	5.14	4.53	3.87
– PROP. REQMT (KG)(1)	470	540	590	571	501	427
• SLEWING PROP. (KG)(2)	30	30	30	30	30	30
• ATTITUDE STAB. & CONTROL PROP. (KG)	57	57	57	57	57	57
TOTAL PROPELLANT (KG)	557/QTR	627/QTR	677/QTR	658/QTR	588/QTR	514/QTR

(1) ASSUMES I_{SP} = 230 SEC STEADY STATE

(2) ONE 90 DEG SLEW/AXIS PER QTR

GRUMMAN

F-366 (SPS-T 139)

SPACE STATION FLIGHT CONTROL SUBSYSTEM

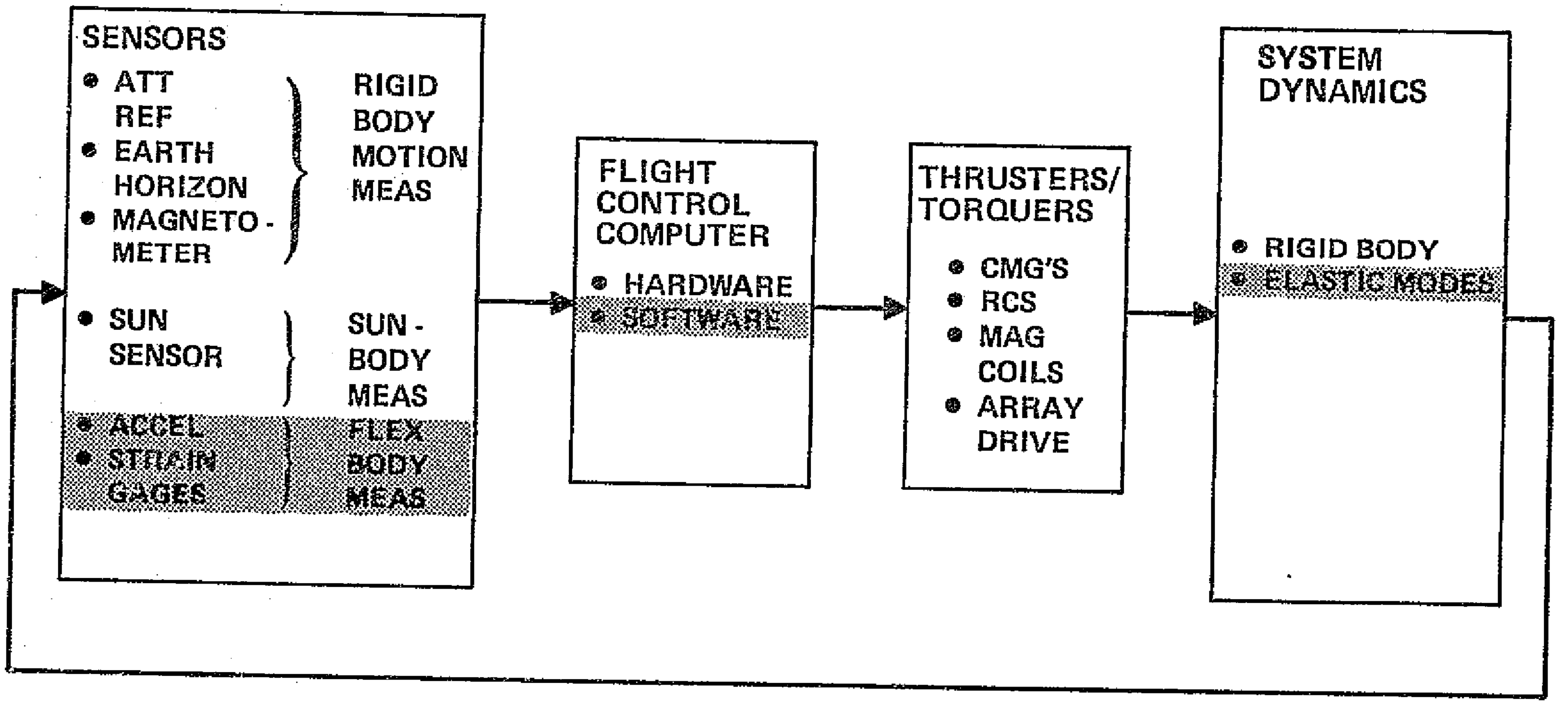
A simplified block diagram shows the overall flow of flight control signals and data between major hardware items.

Elastic structural modes will be addressed by the accelerometer and strain gage sensors which feed their data into the computer. The software therein will determine the torque commands that will stabilize both the rigid and flexible body motion.

F-304T

SPACE STATION FLIGHT CONTROL SUBSYSTEM

"FLEXIBLE FLIER" CONTROL ACCOMODATES SYSTEM FLEXIBILITY



GRUMMAN

F-304

HARDWARE COMMONALITY MATRIX

One of the design goals is to assure that the same set of hardware is used for all flight control functions. This matrix indicates that the commonality design goal has been satisfied. The basic equipment complement has been identified for the stabilization and control function. This basic hardware is also employed to perform the other functions.

F-319T

HARDWARE COMMONALITY MATRIX

SAME COMPONENTS USED FOR SEVERAL FUNCTIONS

ITEM	FLIGHT CONTROL FUNCTION				
	ATT S&C	ALT MAINT	STAT KEEP	SLEWING	ARRAY PTG
SENSORS					
• EARTH HORIZON	•			•	
• SUN	•			•	•
• MAGNETOMETER	•			•	
• ATTITUDE REF UNIT	•			•	
• ACCELEROMETERS	•				
• STRAIN GAGES	•				
COMPUTER	•	•	•	•	•
THRUSTERS/TORQUERS					
• RCS	•	•	•	•	
• CMG'S	•			•	
• MAGNETIC COILS	•			•	
• ARRAY MOTOR DRIVE					•

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BACKUP PROVISIONS FOR SUBSYSTEM RELIABILITY

One criterion for hardware selection is to provide redundant paths for flight control operations. Shown here are the backup provisions that are available if a primary equipment item malfunctions. In certain cases, a degraded level of flight control performance will occur when the backup equipment is in the loop. For base rotational motion and motion damping, two levels of backup are provided.

F-318T

BACKUP PROVISIONS FOR SUBSYSTEM RELIABILITY

FULL BACKUP AVAILABLE

FUNCTIONAL REQUIREMENT	PRIMARY EQUIPMENT	BACKUP PROVISION
ATT ANGLE DETERMINATION	ATT REF UNIT	EARTH HORIZON (EH) AND SUN SENSORS
ATT RATE DETERMINATION	ATT REF UNIT	COMPUTED FROM EH AND SUN SENSOR DATA
STAB/CONTROL COMPUTATIONS	COMPUTER	2ND COMPUTER
BASE ROTATIONAL MOTION	CMG'S*	MAGNETIC COILS OR RCS
BASE TRANSLATIONAL MOTION	RCS	REDUNDANT RCS MODULES
BASE ROT. MOTION DAMPING	CMG'S	RCS

*USED WHEN GRAV GRAD TORQUE IS INEFFECTIVE

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FLIGHT CONTROL SUBSYSTEM FEATURES

During Part 2 of the subject Space Station Study, the concept of a multi-function, low cost flight control subsystem has been developed. The concept takes advantage of gravity gradient to conserve RCS fuel. Large configuration/inertia changes are accommodated by "gain scheduling" in the control algorithm. Moreover, flexible structure modes are stabilized by special computer software which also limits the accelerations and loads that are experienced by the structure.

In an effort to reduce the subsystem development cost and enhance reliability, hardware which has been or will be space proven has been selected. Moreover, reliability has been further enhanced by choosing hardware which can backup certain primary equipment.

FLIGHT CONTROL SUBSYSTEM FEATURES

- BASIC CONTROL CONCEPT SIMILAR FOR WIDE RANGE OF VEH CONFIGS
- DIGITAL CONTROL ALGORITHM INCLUDES "GAIN SCHEDULING" FOR LARGE INERTIA CHANGES
- FLEX STRUCT STAB BY BENDING/TORSION MODE MEASUREMENT COMPUTED KALMAN FILTERING CONTROL ALGORITHM CONTAINS STRUCT ACCEL LIMITING
- GRAV GRAD STAB ACHIEVES MIN LEO PROPEL UTIL
- ALTITUDE MAINT, SLEWING AND STATIONKEEPING FUNCTIONS USE SAME HARDWARE AS STAB AND CONTROL FUNCTIONS
- HARDWARE SELECTION PERMITS BACKUP RECONFIG FOR REDUNDANT OPERATION

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CONCLUSIONS

As a result of the preliminary Flight Control Subsystem design effort, these accomplishments are noteworthy:

- For many periods during LEO Space Station Program options in which precision stabilization is not a requirement, the effective use of natural torques arising from gravity gradient and drag saves RCS propellant which otherwise would be consumed for active control.
- Two modifications to the Space Construction Base configuration have been incorporated which permit increased effectiveness of passive stabilization
- Tentative hardware selection allows commonality of equipment among the flight control functions
- Gain scheduling combined with Kalman filtering and adaptive control techniques, implemented in the computer software, are suggested approaches to the problems of large vehicle configuration/inertia changes and large structure flexibility.

To refine and extend these early results and to verify that the suggested approaches to the vehicle changes and flexibility problems are feasible, it is recommended that Part 3 include these tasks:

- Extend torque estimate analysis to GSO
- Perform 3-axis dynamic simulation on analog computer
  - Include inter-axis coupling
  - Include effects of precession
  - Include effect of Solar Array Motion feedback
  - Evaluate dynamic performance
- Initiate formulation of flexible mode stabilization algorithm.

CONCLUSIONS

- MAKE GRAV GRAD AID STABILIZATION
- MAKE AERO DRAG AID STABLIIZATION
- CONFIGURE VEHICLE TO AID STABILIZATION
- DESIGN FLIGHT CONTROL SUBSYS FOR:
  - HARDWARE COMMONALITY AMONG FUNCTIONS
  - LEO AND GSO OPERATIONS (GOAL)
- DESIGN COMPUTER SOFTWARE TO ACCOUNT FOR:
  - LARGE VEHICLE INERTIA CHANGES
  - FLEXIBILITY OF LARGE STRUCTURE

NEXT STEPS:

- EXTEND ANALYSIS TO GSO
- PERFORM 3-AXIS DYNAMIC SIMULATION
- START FLEXIBLE BODY CONTROL ALGORITHM

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CONSTRUCTION SYSTEM AUX AIDS – HOW MUCH MECHANIZATION

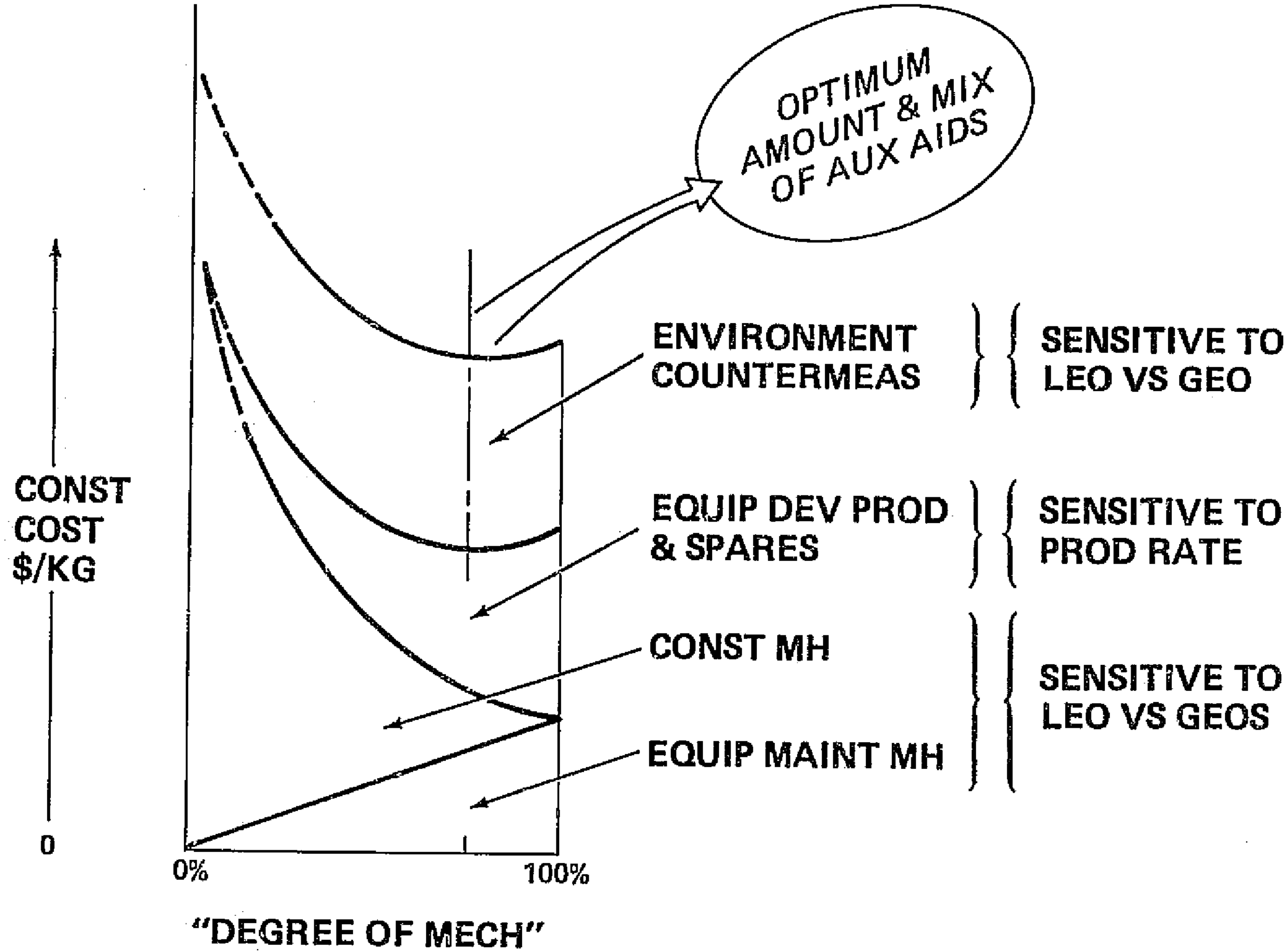
It is assumed that the unit cost of orbital construction is comprised of the elements shown in the chart. An evaluation of the variation of these elements with increasing degrees of mechanization provides the means to logically select the optimum quantities and types of auxiliary aids to be included in construction system definition.

The chart illustrates the qualitative variations of these elements. As man's direct participation diminishes, more equipment of greater sophistication is required, increasing development, production, maintenance and logistic costs. This is compensated, in part, by replacing costly specialized construction man hours with less skilled, more routine maintenance man hours.

The cost of protecting man and equipment against the environment of space is not particularly sensitive to the degree of mechanization. However, the more hostile environment encountered in GEO does increase the cost of these aids as higher levels of mechanization are introduced to minimize the hazards to man.

G-345T

CONSTRUCTION SYSTEM AUX AIDS
HOW MUCH MECHANIZATION



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TYPICAL PHOTOVOLTAIC CONSTRUCTION ELEMENTS

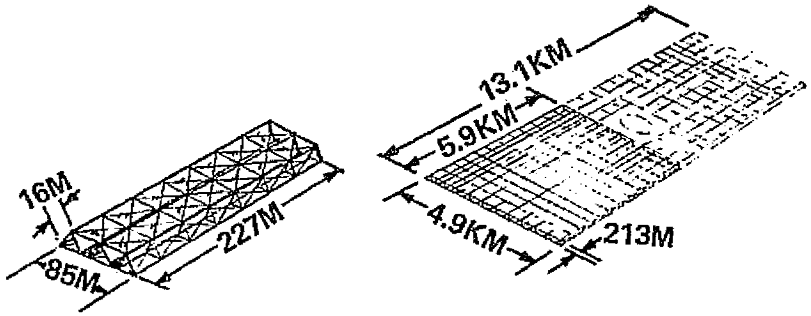
Based upon the Solar Power Demonstration Article (SPDA) proposed for the mid-1980 time frame, and the full size Solar Power System of the mid-1990's as models, the size and mass of typical construction elements are determined.

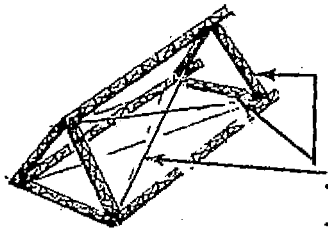
Although the SPS is several orders of magnitude larger than the SPDA, there are elements in both structures of comparable mass (the SPDA triangular frame assembly and the SPS posts and lower lateral beams), as well as many common assembly tasks (joining, aligning, rigging, etc).

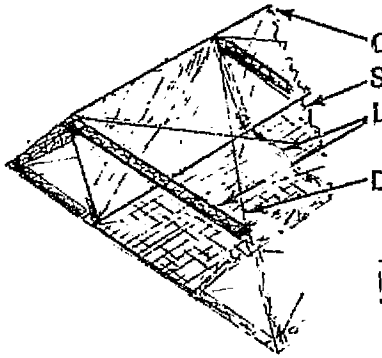
Thus, some handling and assembly aids developed for the SPDA construction would find application, with little modification, in the construction tasks of the subsequent decade.

TYPICAL PHOTOVOLTAIC CONSTRUCTION ELEMENTS

- LARGE SCALE GROWTH TO FULL SIZE DEV.
- USE INITIAL AIDS IN FULL SIZE DEV?







	MID 80's SPDA		MID 90's FULL SIZE SPS	
		WT(KG)		WT(KG)
GIRDER – CONTINUOUS –	3 X 192.5	= 578	3 X 24000	= 72000
OR		OR		OR
– SEGMENTED –	21 X 27.5	= 578	36 X 2000	= 72000
POSTS –	24 X 13.75	= 330	39 X 1000	= 39000
DIAGONAL WIRES –	42 X 0.5	= 21	72 X 192	= 13800
TRIANGULAR FRAME		929		125,800
CONCENTRATOR FILM –	75/SIDE		29000/SIDE	
SOLAR CELL BLANKETS –	1890/BAY		760000/BAY	
LATERAL BEAMS – UPPER –	27.5		2000	
– LOWER –	13.6		1000	
DIAGONAL WIRES – UPPER –	0.65		·245	
– LOWER –	0.50		192	
SOLAR ARRAY	80 X 227.5M	= 7,565	4.9 X 5.9KM	$= 10.1 \times 10^6$

GRUMMAN

G-310

CONSTRUCTION AIDS – AUXILIARY AID CATEGORIES

The construction system begins with a stable, rigid orbiting platform which provides support for the auxiliary aids and a variety of special purpose modules. Auxiliary aids are that wide range of tools and equipment necessary to perform orbital fabrication and construction tasks. Three categories of these aids are listed in the chart.

Support varies from physical mounting to supplying power, cooling, data handling and maintenance.

G-309T

CONSTRUCTION SYSTEM
AUXILIARY AID CATEGORIES

- **AUTO FAB MODULE**
  - MAINTENANCE
  - RESUPPLY
- **MOBILE ASSEMBLY AIDS**
  - MAINTENANCE
  - RESUPPLY
- **MISCELLANEOUS AIDS**
  - ALIGNMENT AIDS
  - ZERO G HAND TOOLS
  - TEST AND CHECKOUT EQUIPMENT
  - SUN SHADES
  - LIGHTING
  - REMOTE VIEWING

GRUMMAN

TYPICAL MID '80's CONSTRUCTION SYSTEM (SPS SUBSCALE)

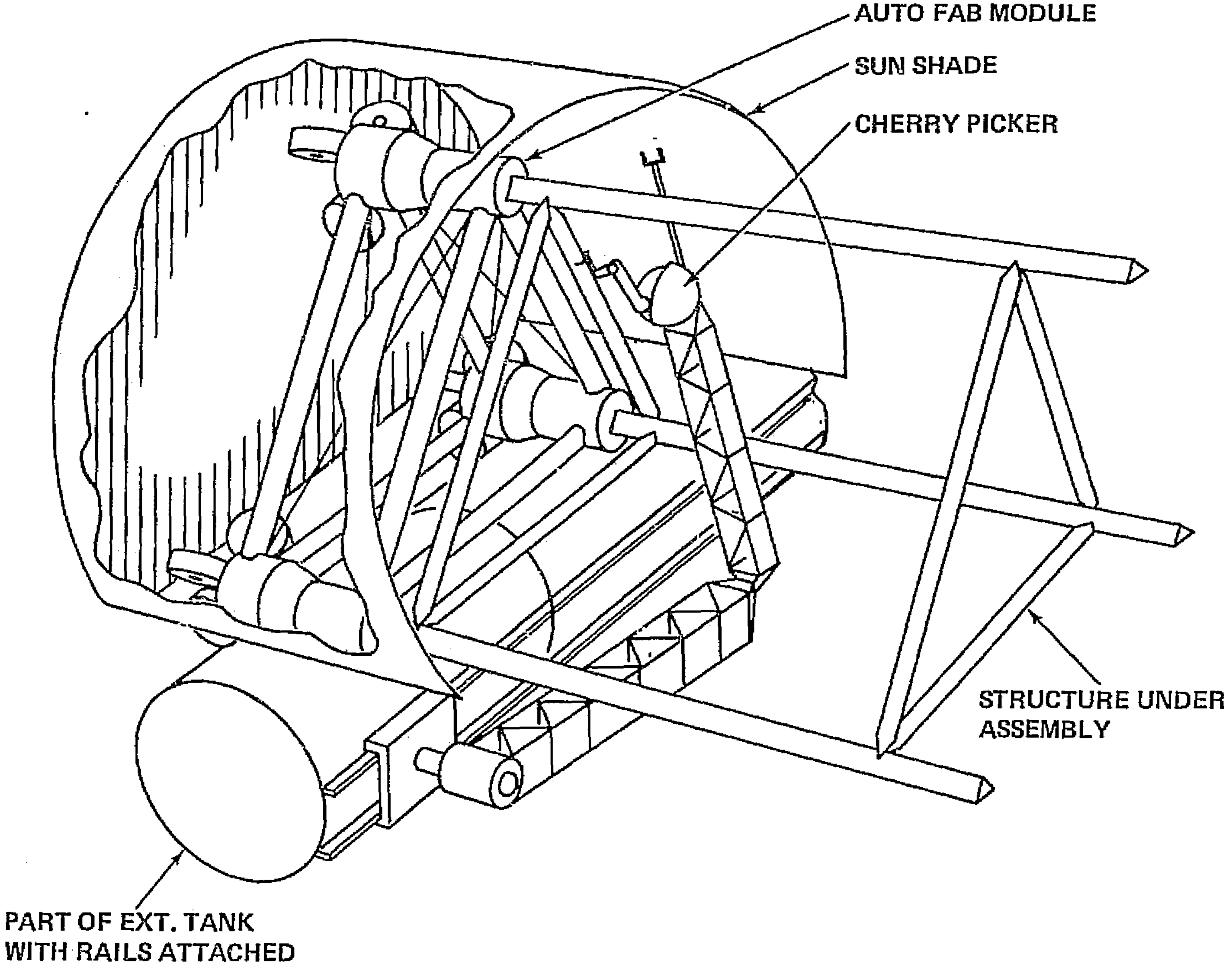
The system shown employs the same construction principles as will the full size SPS SCB. It is configured primarily to build the 2 mw SPDA.

Three fabrication modules are structurally interconnected in their correct relative positions. Two of them are mounted to the structural spine of the SCB. Each module spews out a continuous 1m beam made from three rolls of stock material. A Cherry Picker, with man operated short arm manipulators at its tip, assembles 1m cross beams and wire braces the structure. The cross beams have been produced previously by the fabrication modules and stowed on the structural spine.

A sun shade covers the construction facility to minimize thermal distortion of the jig positioned support structure for the fabrication modules. Distortion of this structure could result in nonparallel continuous beams.

G-374T

TYPICAL MID '80s CONSTRUCTION SYSTEM – SPS SUBSCALE



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GRUMMAN

G-374
J-198

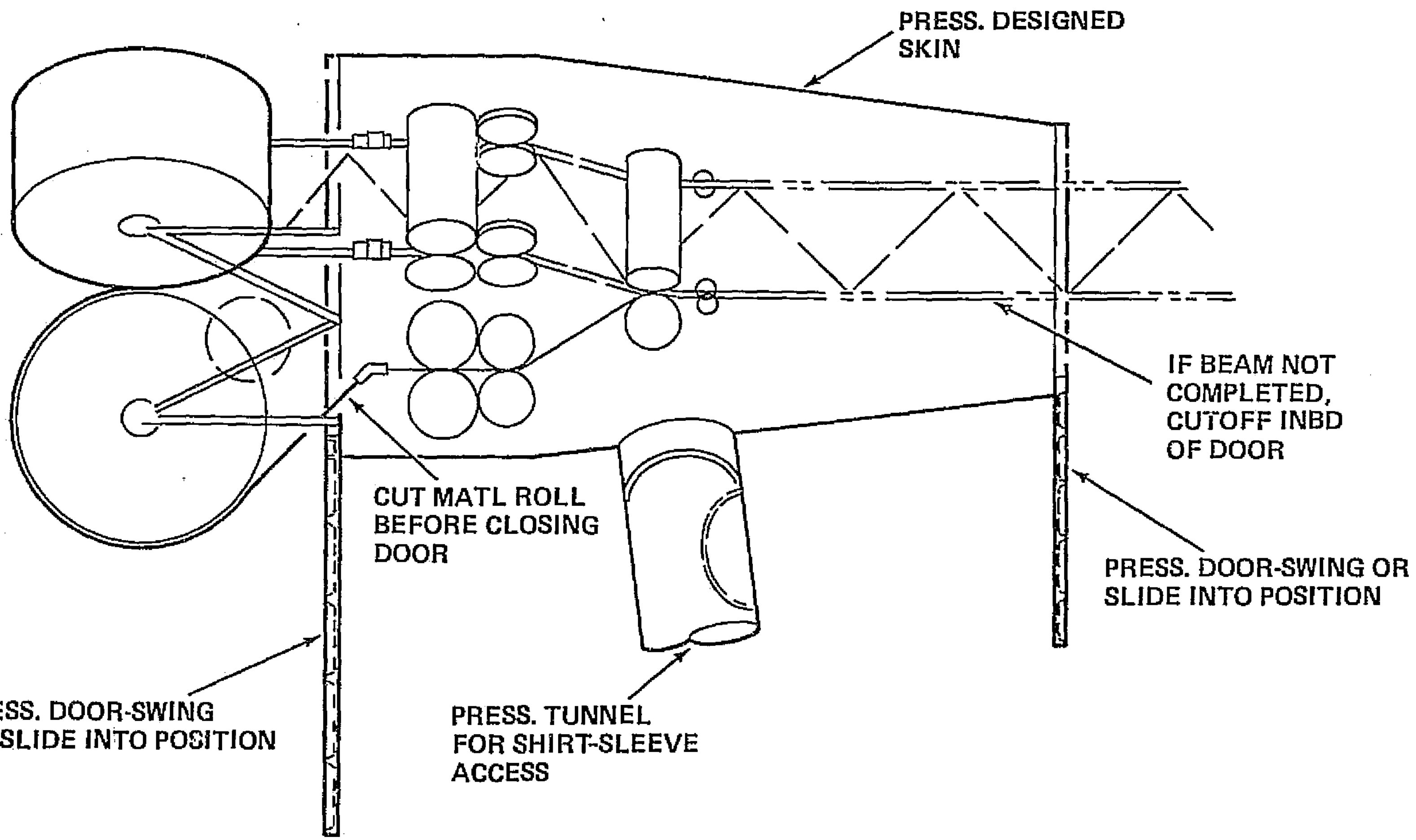
AUTO FAB MODULE SERVICING OPTION – SHIRTSLEEVE SERVICING

An alternate to EVA servicing of Space Fabrication Modules is to enclose the module in a pressurized shell. Man can then operate in a shirt-sleeve environment. The concept shown has a pressure designed skin to cover the main body of the facility with a closure door at each end. At the material roll end, the material must be cut before the door covering that end is swung into position. Where the manufactured beam emanates, if it is a servicing operation, the door can be closed when a completed beam has been removed. If it is a repair, and an incompleted beam is in position, then the beam must be cut before the door can be closed.

A tunnel connecting the pressure shell to the habitation facility gives complete shirt sleeve access.

G-349T

AUTO FAB MODULE SERVICING OPTION
SHIRT – SLEEVE SERVICING



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GRUMMAN

G-349

AUTO FAB MODULE SERVICING OPTION – EVA SERVICING

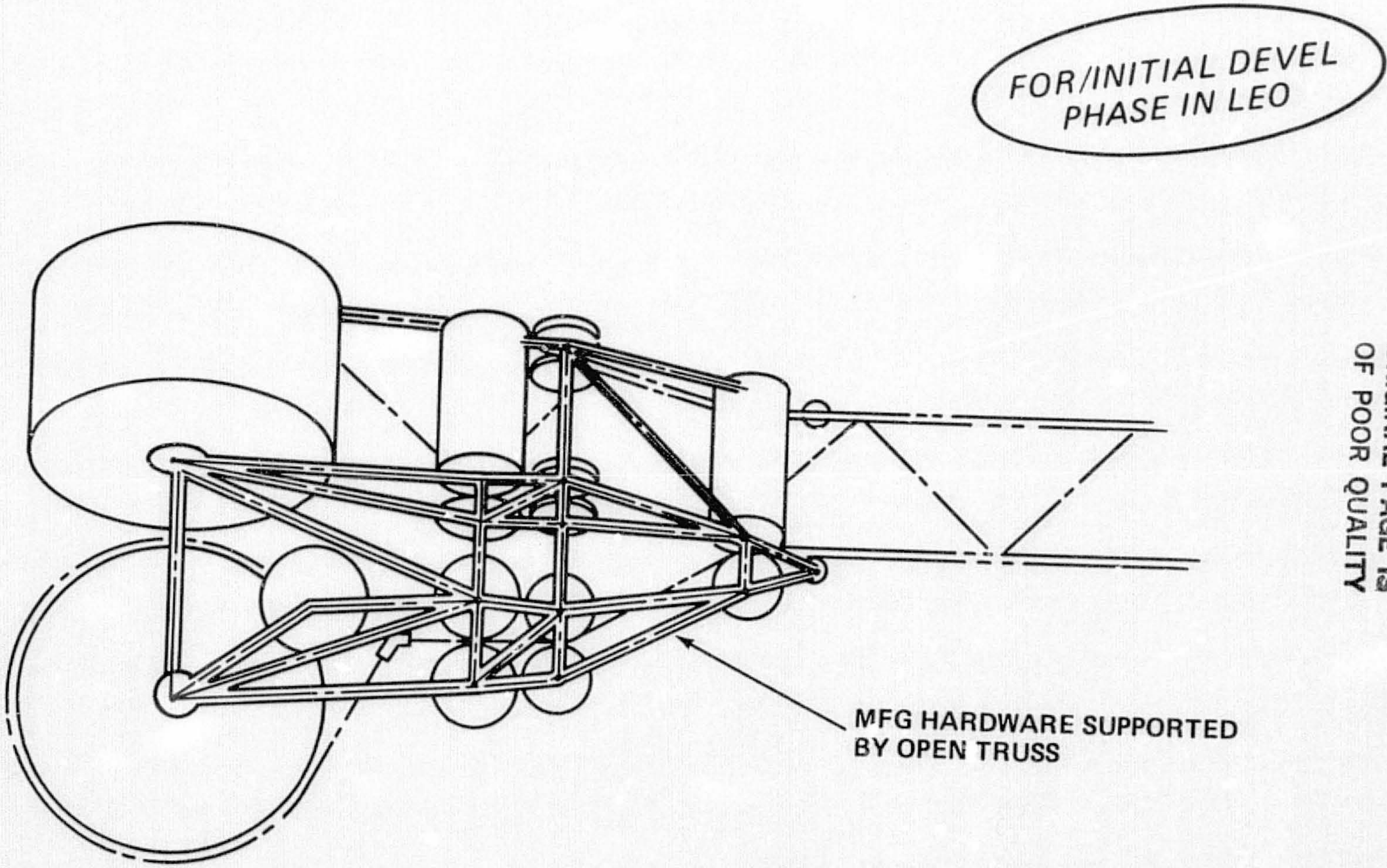
Manned service or repair of a space fabrication module can be performed either by EVA or by man in shirt-sleeves. This chart assumes EVA servicing.

To provide ready access to component parts, the module hardware is supported by open trusswork. This approach is assumed for the initial development phase in LEO.

G-348T

AUTO FAB MODULE SERVICING OPTION
EVA SERVICING

C-4



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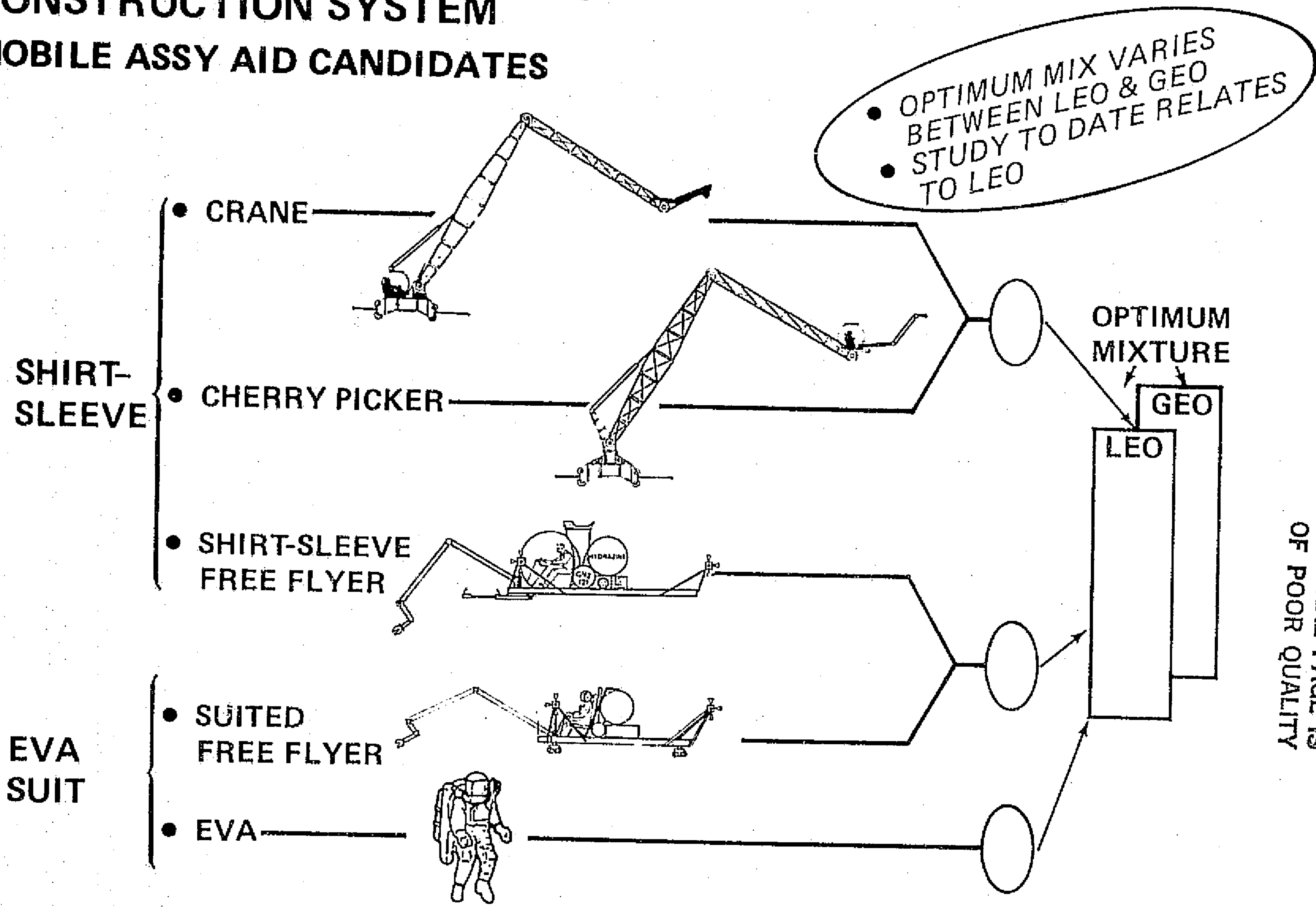
AUXILIARY AIDS – MOBILE ASSEMBLY AID CANDIDATES

In the category of mobile assembly aids, several candidate concepts are pictured here. Configured to perform the tasks of handling, positioning, joining and to a limited extent, transporting, these concepts utilize man directly and remotely, in a shirt-sleeve environment or EVA mode.

The optimum mix of aids results from identifying the characteristics of each concept, evaluating the application of these characteristics to the function to be performed, screening these results and selecting the prime candidates, and finally effectively allocating these functions among the selected aids.

G-320T

CONSTRUCTION SYSTEM
MOBILE ASSY AID CANDIDATES



GRUMMAN

G-320

MOBILITY AIDS – SHIRTSLEEVE FREE FLYER

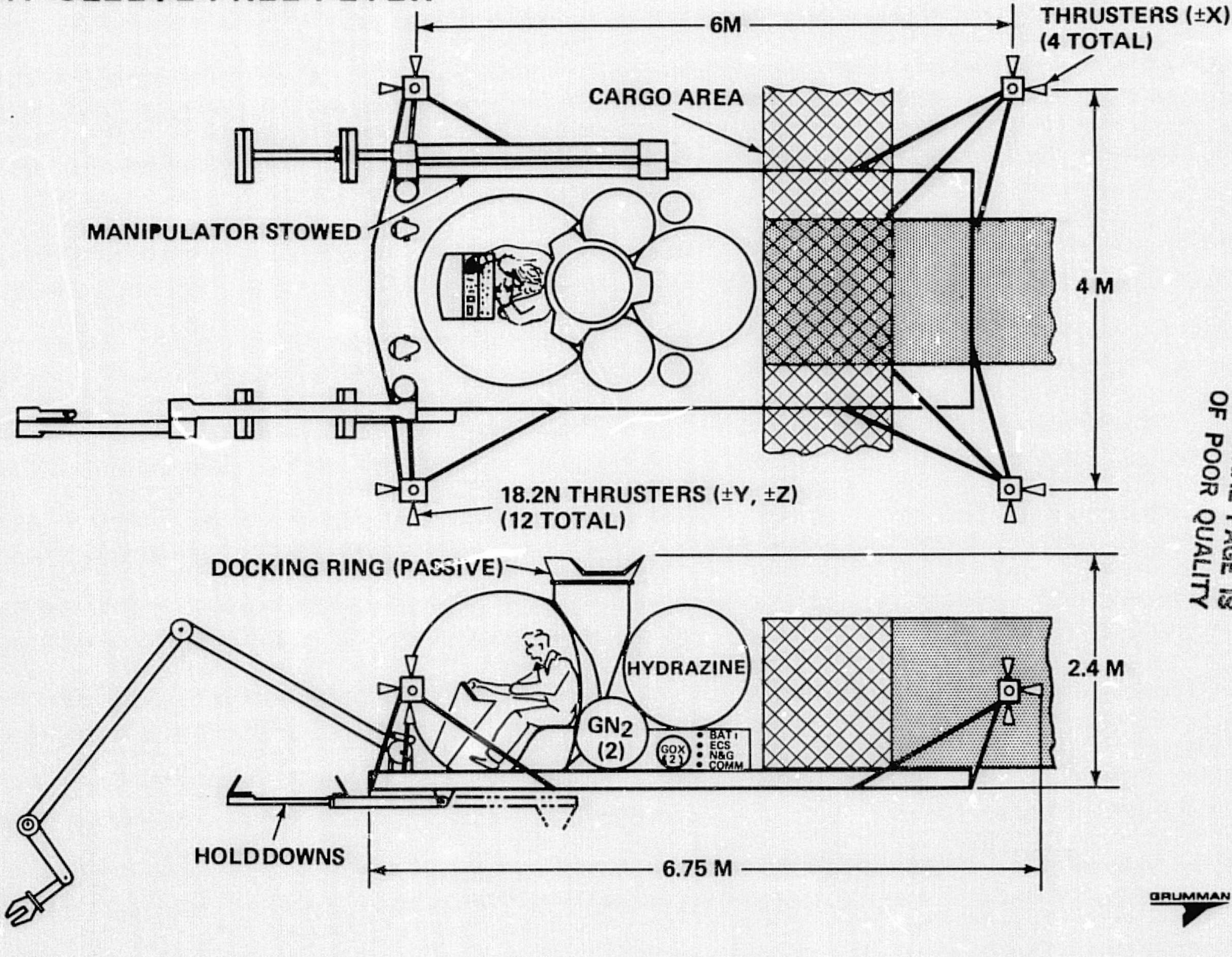
The single crewman is housed in a pressurized shirt sleeve environment. Heat is rejected through a glycol heat exchanger/water sublimator system using approximately 10 kg of water per sortie. Lithium hydroxide is used for air revitalization and a docking interface provides access between the pressurized bubble and the crew modules of the Space Construction Base.

A holddown system provides a positive reaction for the manipulator loads to allow more precise positioning and alignment of construction elements.

Manipulator and propulsion systems are identical to those for the Suited Free Flyer.

G-307T

MOBILITY AIDS
SHIRT-SLEEVE FREE FLYER



GRUMMAN

SHIRT SLEEVE FREE FLYER – WEIGHT AND PERFORMANCE ESTIMATES

The Shirt-Sleeve Free Flyer is sized to provide the same capability as the Suited Free Flyer. Pre-EVA preparation is not needed and the design sortie duration can therefore, be extended. A duration of 8 hr is selected.

The increase in electrical energy required reflects the longer duration sortie, as well as the increase in average electrical power level necessary for the environmental control, life support and other subsystems.

Approximately 1080 kg of consumables are required for each sortie.

G-322T

SHIRT SLEEVE FREE FLYER
WEIGHT AND PERFORMANCE ESTIMATES

WEIGHT (KG)		PERFORMANCE	
STRUCTURE/MECHANISMS		PROPULSION	
– MANIPULATORS & HOLD DOWNS	280	THRUST LEVEL ± X	89 N
– DOCKING ASSY (PASSIVE)	146	± Y	36 N
– SHIRT SLEEVE BUBBLE	350	± Z	72 N
– OTHER STRUCTURE	343		
PROPULSION SYSTEM	247	ACCEL (1000 KG PL)-MAX	2.59×10^{-3} G
ELECTRICAL POWER	480	-MIN	1.98×10^{-3} G
CONTROLS, AVIONICS, ECLS	90	TOTAL ΔV (1000 KG PL)	619 M/SEC
CONTINGENCY (25%)	484	ASSUMED DUTY CYCLE	20%
SUBTOTAL (DRY WEIGHT)	2,420	ELECTRICAL ENERGY (BATTERIES)	16 KWH
PROPELLANTS/GASES	1,078	MANIPULATOR EXTENSION, MAX	7 M
CREW	77	LAUNCH VOL (THRUSTERS FOLDED)	35 M^3
GROSS WT (ZERO PL)	3,575	PL BAY LENGTH USED	6 M
		DESIGN SORTIE DURATION	8 HR

GRUMMAN

G-322

MOBILITY AIDS – SUITED FREE FLYER

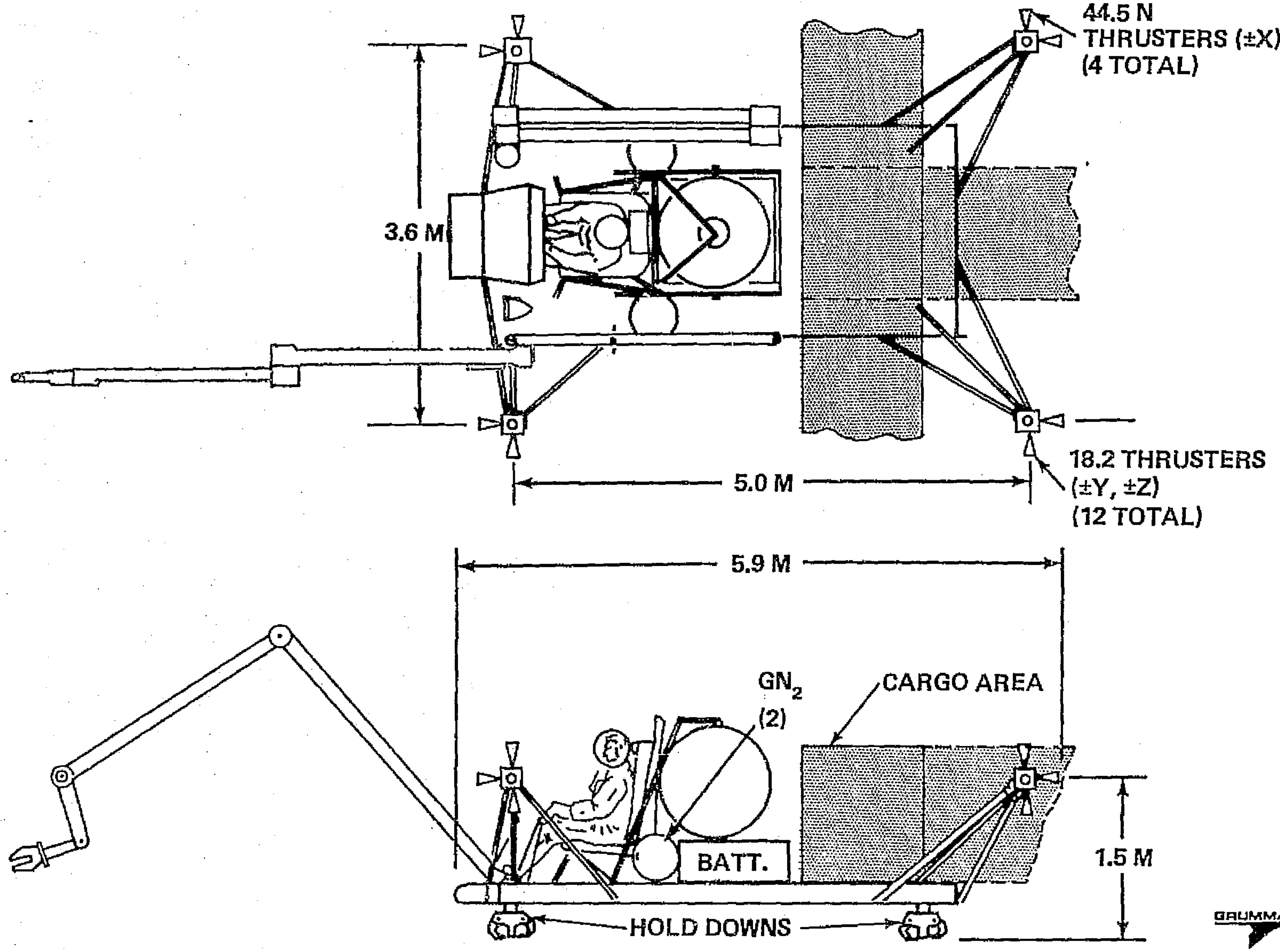
Piloted by a crewman in an Extra-Vehicular Activity (EVA) suit plus backpack, this flyer provides the means to extend the range of EVA, to handle and position moderately sized construction elements with rough accuracy and, with its holddowns anchored, to align structural members and join them using its manipulators.

The monopropellant propulsion system uses gaseous nitrogen for positive propellant expulsion, hydrazine propellant and catalytic ignition engines.

Electrical energy is supplied by battery.

G-308T

MOBILITY AIDS
SUITED FREE FLYER



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GRUMMAN

G-308

SUITED FREE FLYER – WEIGHT AND PERFORMANCE ESTIMATES

Sizing of the Suited Free Flyer is based on a six hr sortie duration (back-pack limited) and a propulsion duty cycle of 20%. Payload weights up to 1000 KG can be transported with reasonable performance.

Approximately 770 kg of consumables are required for each sortie. For a duty cycle of 10% this quantity reduces to approximately 400 kg and total ΔV, with a 1000 kg payload, decreases to 340 m/sec.

G-323T

SUITED FREE FLYER
WEIGHT AND PERFORMANCE ESTIMATES

WEIGHT, KG		PERFORMANCE	
STRUCTURE/MECHANISMS		PROPULSION	
– MANIPULATORS & HOLD DOWNS	290	THRUST LEVEL ± X	89 N
– DOCKING ASSY	–	± Y	36 N
– SHIRT SLEEVE BUBBLE	–	± Z	72 N
– OTHER STRUCTURE	272	ACCEL (1000 KG PL)-MAX	3.62×10^{-3} G
PROPULSION SYSTEM	210	-MIN	2.77×10^{-3} G
ELECTRICAL POWER	288	TOTAL ΔV (1000 KG PL)	618 M/SEC
CONTROLS, AVIONICS, ECLS	40	ASSUMED DUTY CYCLE	20%
CONTINGENCY (25%)	275	ELECTRICAL ENERGY (BATTERIES)	10 KWH
SUBTOTAL (DRY WEIGHT)	1,375	MANIPULATOR EXTENSION, MAX	7 M
PROPELLANTS/GASES	771	LAUNCH VOL (THRUSTERS FOLDED)	20 M^3
CREW (SUITED PLUS BACK PACK)	130	PL BAY LENGTH USED	5 M
GROSS WT (ZERO P L)	2,276	DESIGN SORTIE DURATION	6 HR

GRUMMAN

G-323

MOBILITY AIDS – CHERRY PICKER

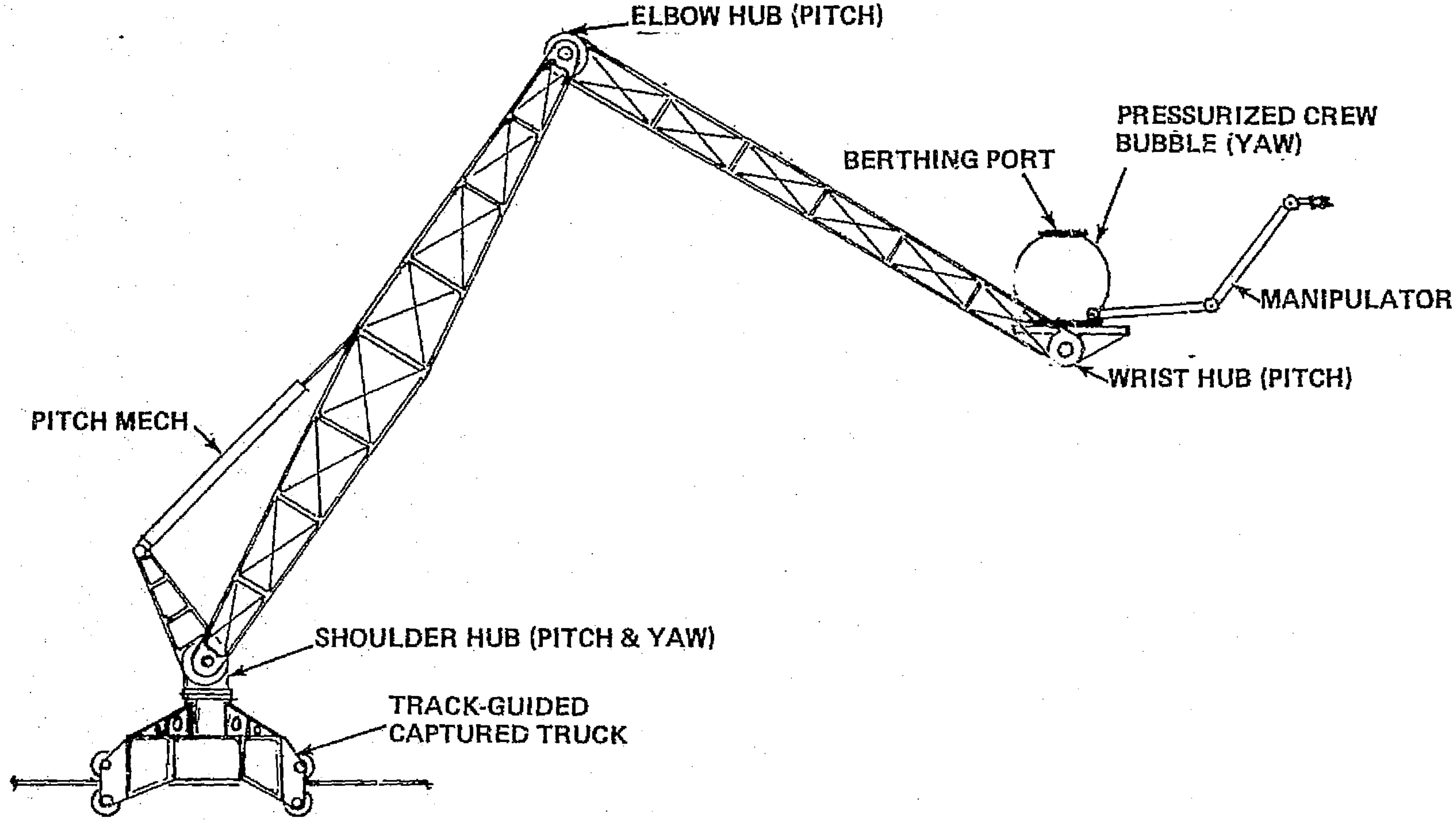
The Cherry Picker is mounted on rails attached to the construction base spine. The rails are captured between four pairs of wheels providing positive reaction to manipulator loads. Electrical power from the Space Construction Base (SCB) system drives the crane. Rotary actuators power each hub except for pitch motion at the shoulder where a linear actuator is used.

A pressurized bubble provides a shirtsleeve environment for the one man crew. Access is through the berthing port which is positioned, by the Cherry Picker arms, and then attached to a similar port in the crew modules.

A manipulator system, controlled by the crewman, is mounted to the bubble platform. This configuration provides 11 degrees of freedom at the manipulator end effector. Further study is necessary to determine the exact number of degrees of freedom required.

G-321T

MOBILITY AIDS – CHERRY PICKER



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GRUMMAN

G-321

CHERRY PICKER — WEIGHT AND PERFORMANCE ESTIMATES

Resupply requirements for this configuration are small. However, the Cherry Picker occupies 16 m of the orbiter payload bay length when packaged for delivery to orbit. Although restructed in range to the length of its tracks, its 30-m reach provides access to all areas where assembly and handling functions are performed in LEO construction scenarios. It places man in direct view of the manipulator action and, with crane arms locked, provides a stable platform for critical aligning and joining operations.

A design sortie duration of eight hr is selected in this configuration. Longer duration sorties are available for a modest increase in consumable quantities and virtually no impact on the design.

CHERRY PICKER
WEIGHT AND PERFORMANCE ESTIMATES

WEIGHT, KG		PERFORMANCE	
STRUCTURE/MECHANISMS		ELECTRICAL POWER REQ'TS (SCB SUPPLIED)	2 KW AVG
– MANIPULATOR & HOLD DOWNS	200		
– SHIRT SLEEVE BUBBLE	350	MAX EXTENSION	
– BERTHING PORT	105	– CRANE ARMS	23 M
– OTHER STRUCTURE	1,585	– MANIPULATOR	7 M
PROPULSION SYSTEM	–	LAUNCH VOLUME	113 M^3
ELECTRICAL POWER SYSTEM	–	(DISASSEMBLED & FOLDED)	
CONTROLS, AVIONICS, ECLS	120	LENGTH OF P.L. BAY USED	16 M
CONTINGENCY (25%)	590	DESIGN SORTIE DURATION	8 HRS
SUBTOTAL–DRY WT	2,950		
GASES	15		
CREW	77		
GROSS WT (ZERO P L)	3,042		

GRUMMAN

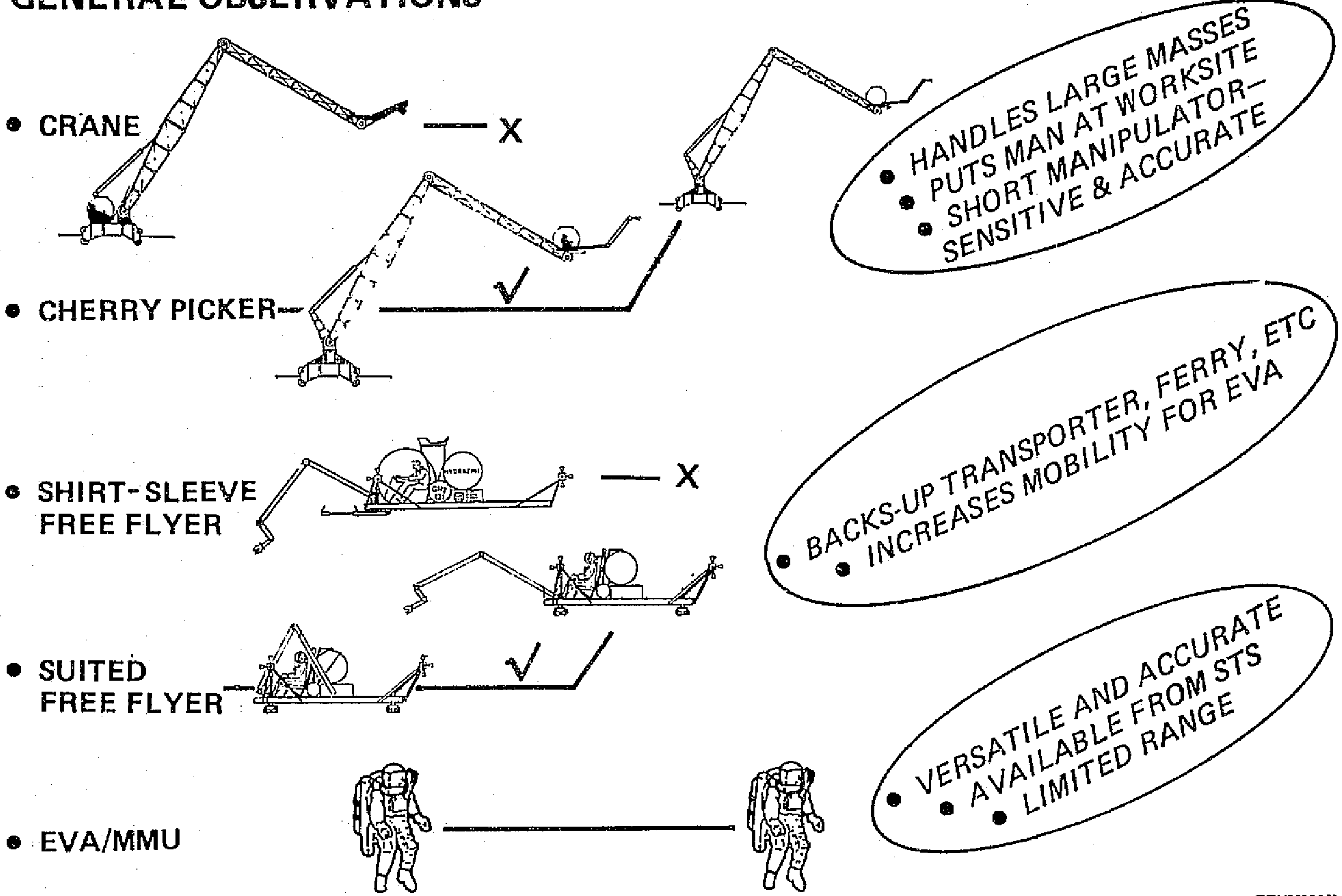
G-358

MOBILE ASSEMBLY AIDS – GENERAL OBSERVATIONS

Assessment of the presently defined characteristics of the Candidate Mobile Assembly Aids has led to the preliminary selection depicted on the chart.

G-357T

MOBILE ASSY AIDS
GENERAL OBSERVATIONS



AUXILIARY AIDS – APPLICATIONS MATRIX

A matrix such as depicted in the chart is used to relate particular construction functions and characteristics of the candidate auxiliary aids. Thus, for each candidate a collection of characteristics is identified which are then translated into preliminary design requirements. Configuring each aid to its particular requirement allows a comparison of the functional effectiveness of each aid to perform the construction tasks and permits the selection of the most effective. From these data, design specifications are generated and an effective mix of aids for space construction is defined.

G-359T

AUXILIARY AIDS – APPLICATIONS MATRIX

TASK \ AID	CHERRY PICKER	EVA/FREE FLYER	EVA/MMU	EVA	REMOTE VIEWING	SPECIAL PURPOSE AIDS	ALIGNMENT AIDS	GENERAL PURPOSE AIDS
TRANSPORT	X							
HANDLING	X		X	X				
INSTALLING	X		X	X		X		
JOINING	X			X		X		
RIGGING				X		X	X	
ALIGNING	X			X			X	
TESTING			X	X	X	X		
CHECKOUT					X	X		
INSPECTING		X			X			
MONITORING								
SERVICE								

- RELATES TASK TO AUX AID FUNCTION
- BASIS FOR DEFINING AID MIX & DESIGN REQMTS

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G-359

VOLUME 2 – PROGRAM OPTIONS

PROGRAM OPTIONS
DEFINITION &
INTEGRATED REQUIREMENTS
ROSS FLEISIG

SPACE
CONSTRUCTION
BASE
JOE GOODWIN

CONCEPT DEVELOPMENT
JOE GOODWIN/ROSS FLEISIG

COMPARATIVE EVALUATION
RON MCCAFFREY/JOE GOODWIN

PROGRESSIVE DEVELOPMENT
OPTIONS
RON MCCAFFREY

TRANSPORTATION
RON BOYLAND

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K-316(A)

SSSA – CRITERIA FOR PART 2 COMPARATIVE EVALUATION

- ENGINEERING COMP
- COST
- TRANSPORT IMPACT
- BUDGET REQMTS
- MISSIONS
- TECHNOLOGY STATUS
- GROWTH POTENTIAL
- PROGRAM FLEXIBILITY

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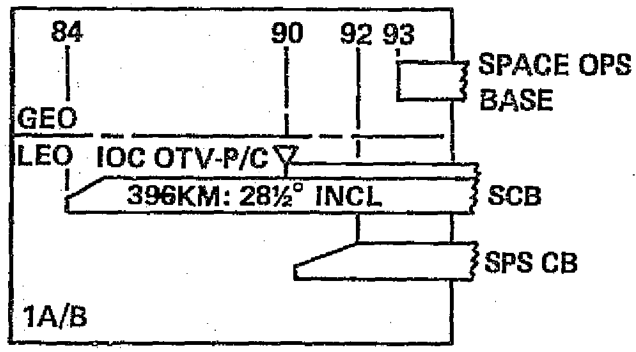
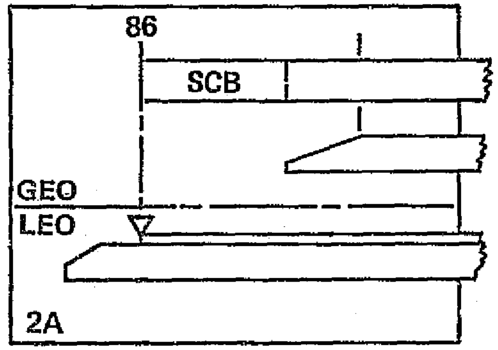
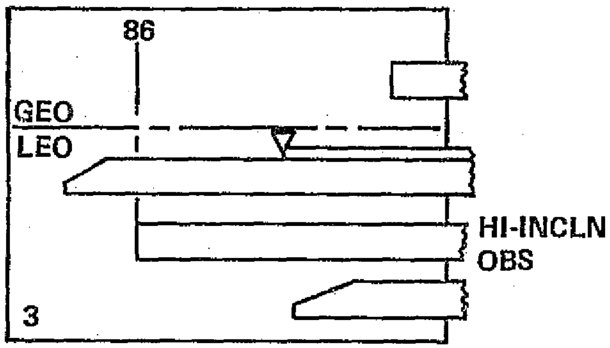
PROGRAM OPTION – MAJOR CHARACTERISTICS

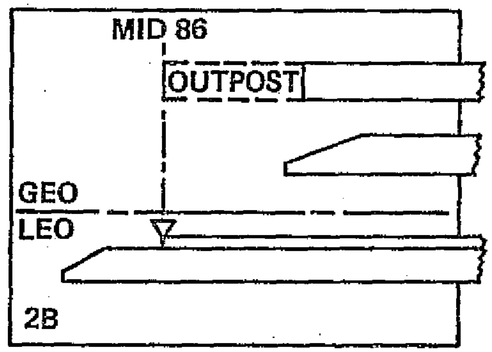
FULL SIZE SPS ASSY PLANNED FOR LEO



FULL SIZE SPS ASSY PLANNED FOR GEO







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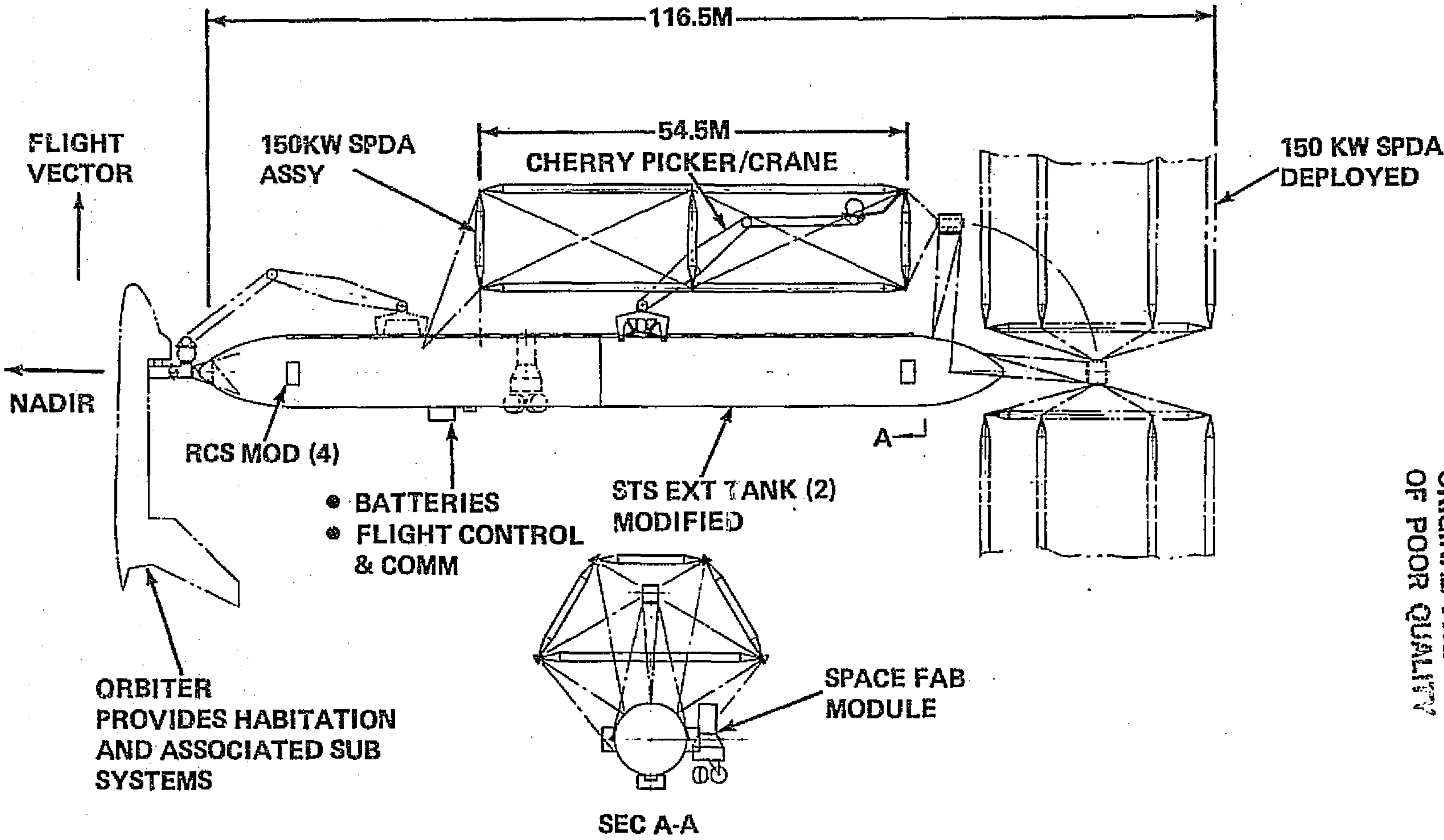
G-339

TENDED SPACE CONSTRUCTION BASE

LOW EARTH ORBIT, 28½ DEG INCLINATION



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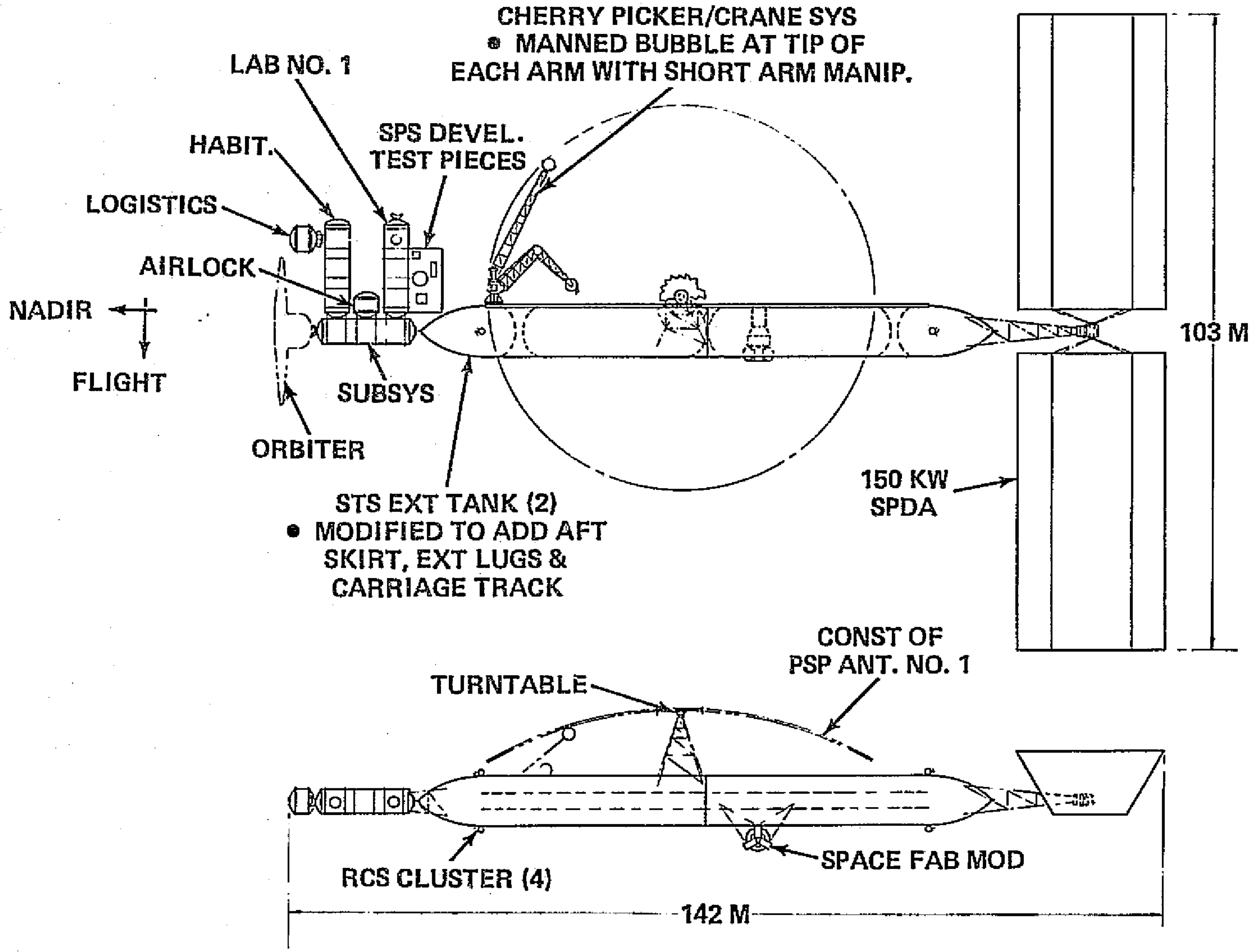
WC-329

INITIAL SPACE CONSTRUCTION BASE
LEO, 28½ DEG INCL - OPTION 1A/B, 2A/B & 3



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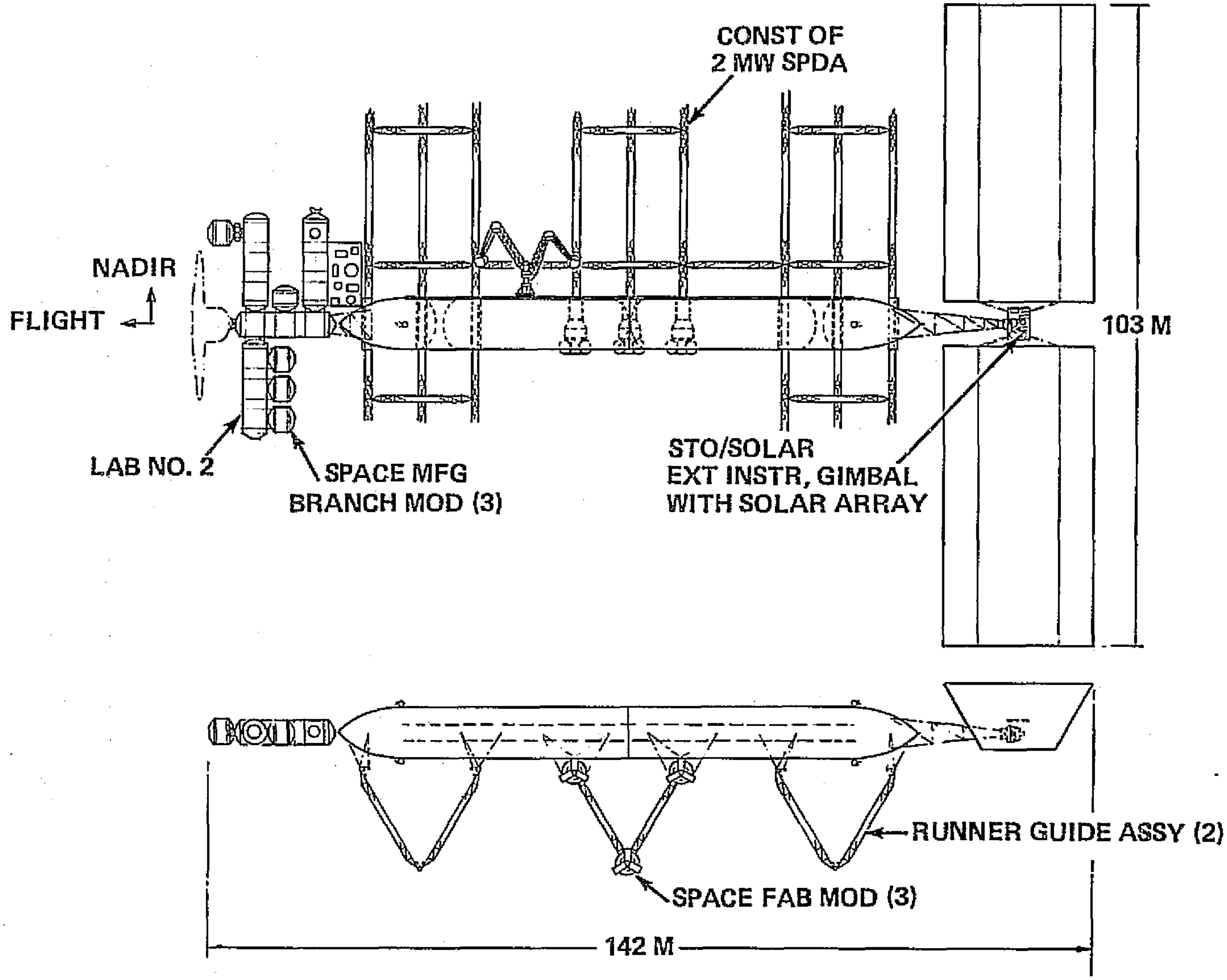
ADVANCED SPACE CONSTRUCTION BASE

LEO, 28½ DEG INCL 1A/B & 2B



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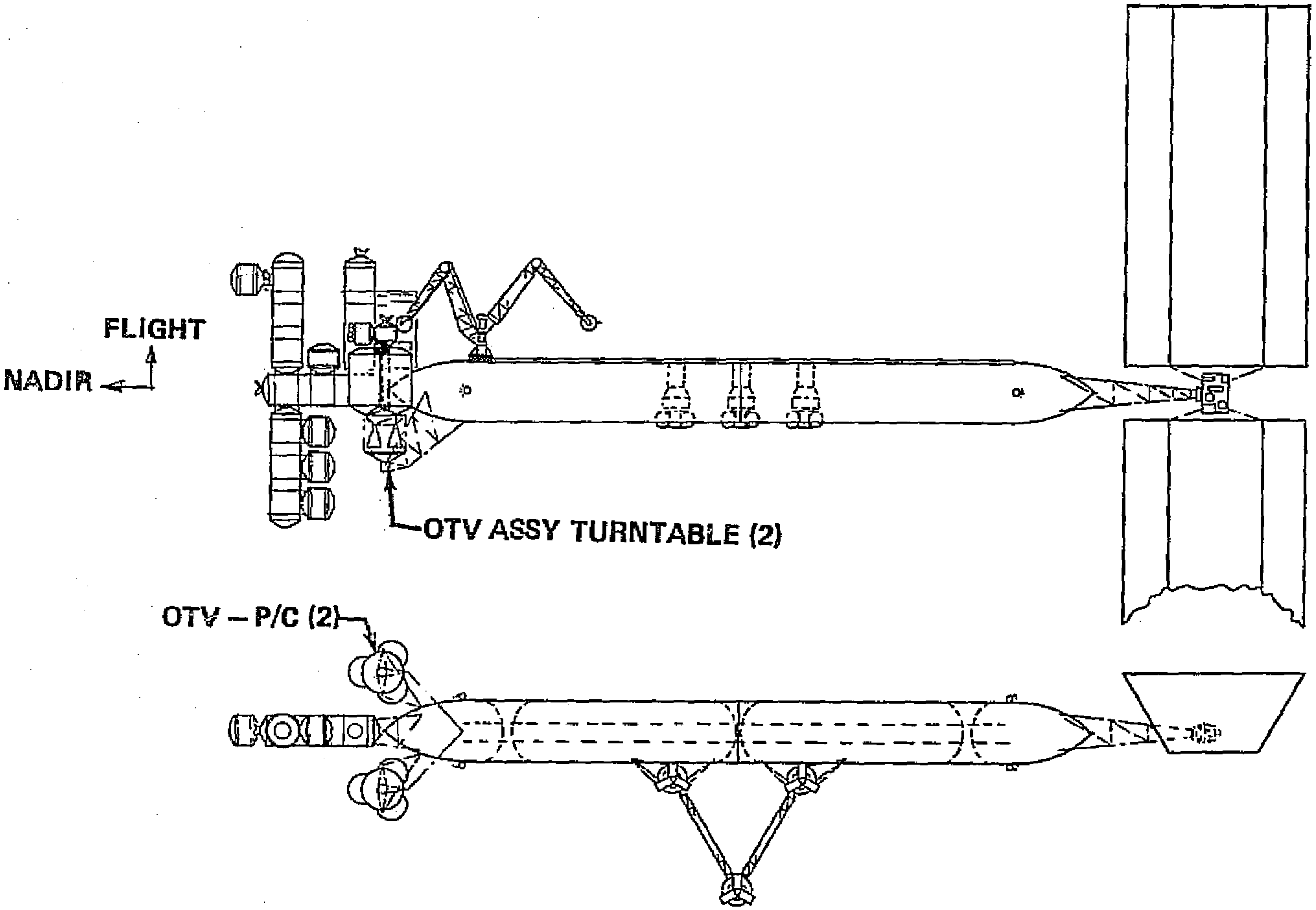
ORBITAL DEPOT
LEO, 28½ DEG INCL - OPTION 1A/B, 2A/B & 3



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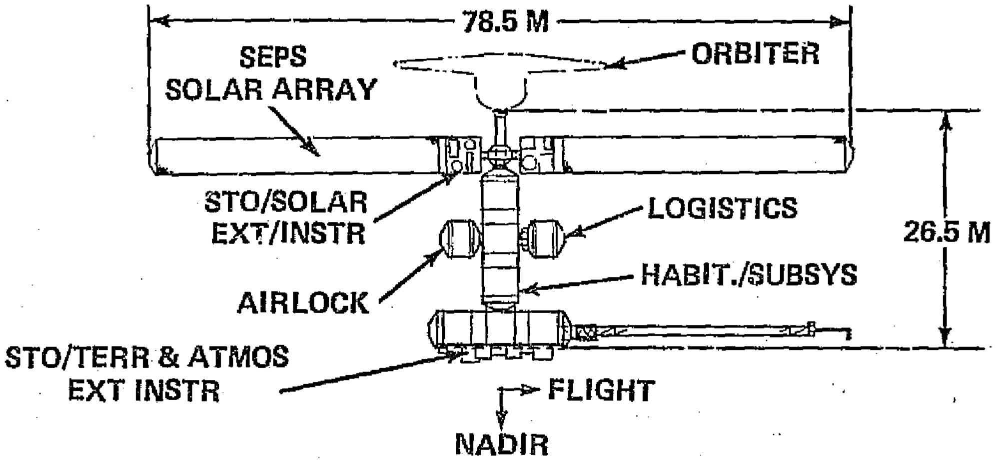
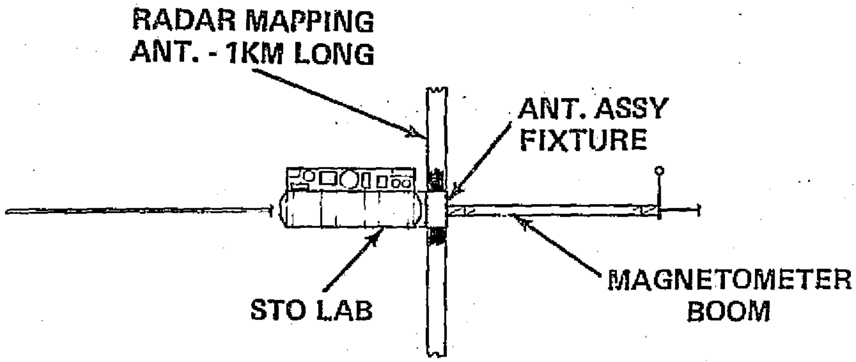
BASE:
LEO HIGH INCLN – OPTION 3





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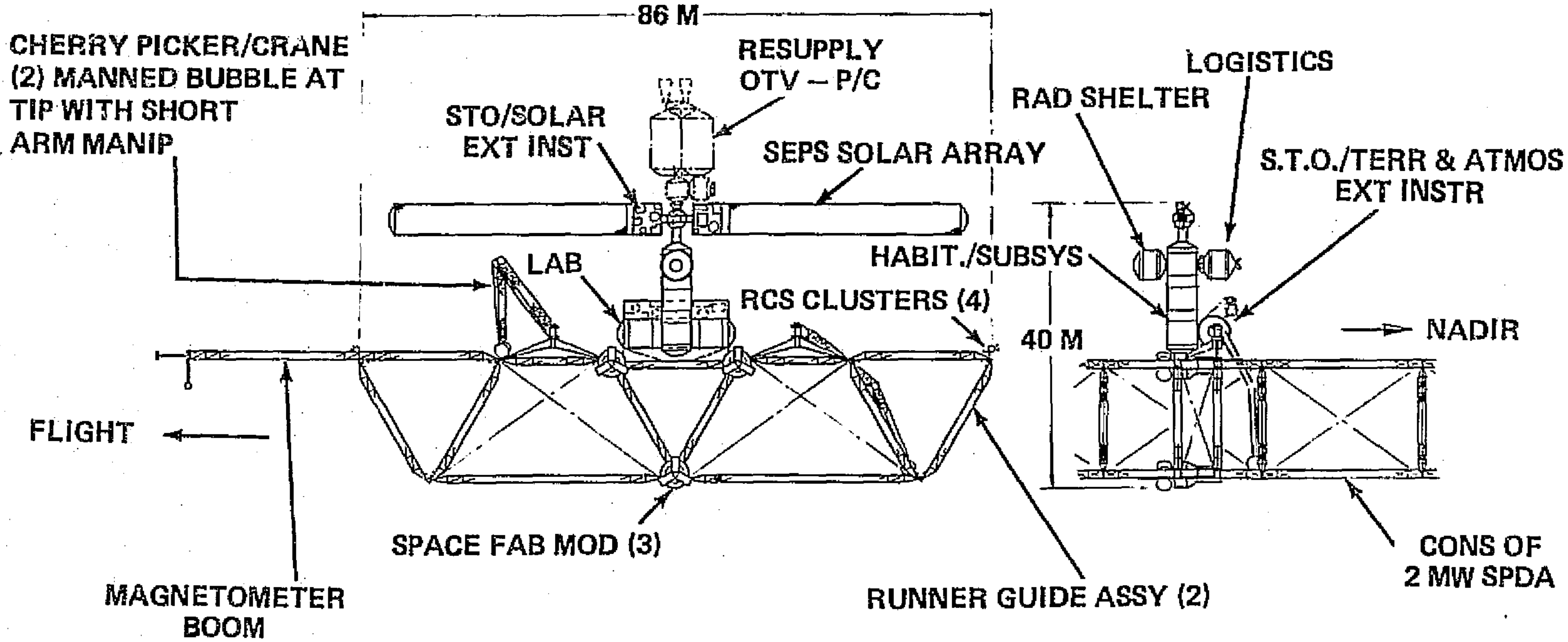
SPACE CONSTRUCTION BASE
GEOSTATIONARY ORBIT - OPTION 2A



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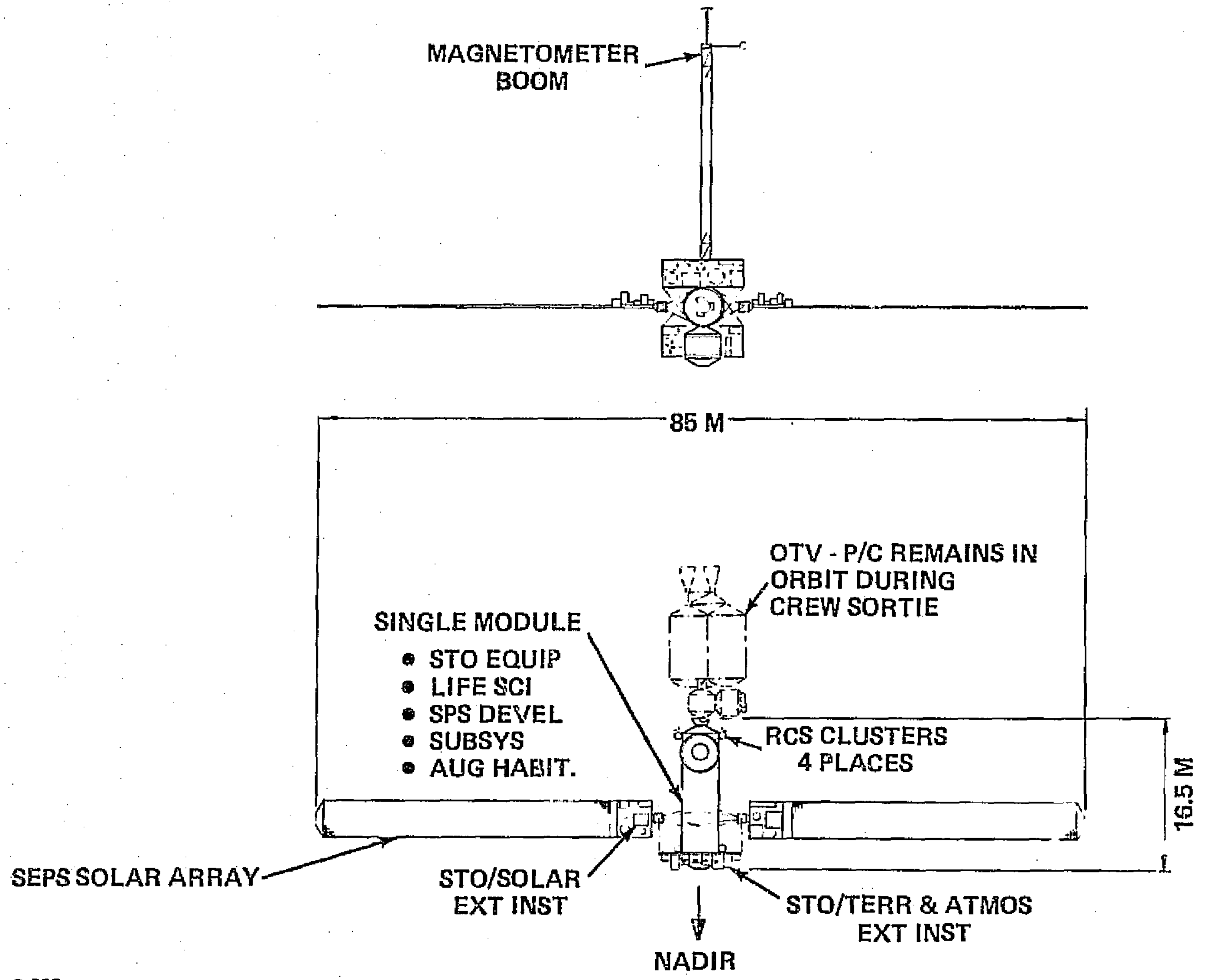
OUTPOST
GEOSTATIONARY ORBIT OPTION 2B



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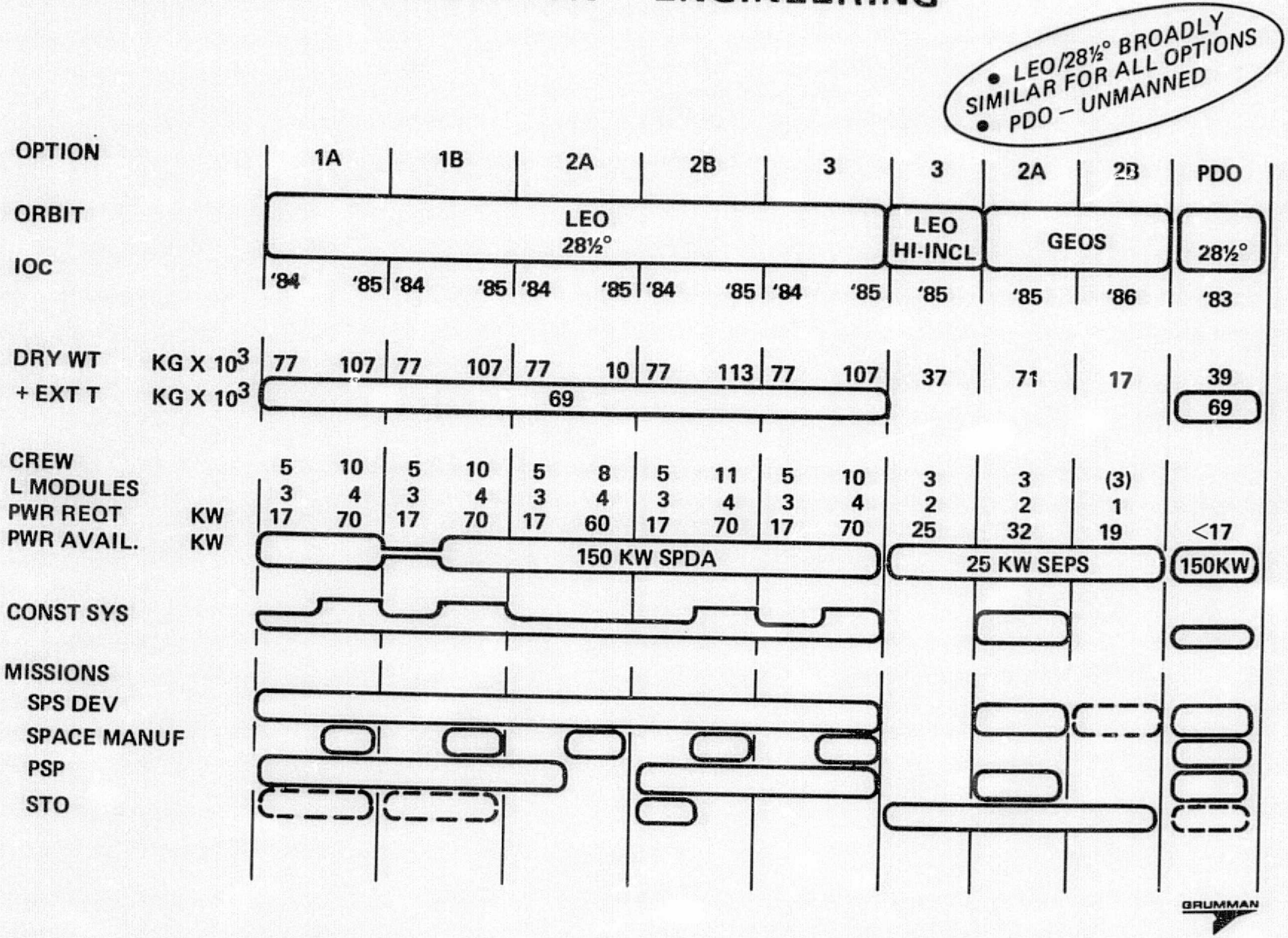
COMPARATIVE EVALUATION – ENGINEERING

The initial construction base satisfies all options in 28½° LEO and is fundamentally the same for all options. Similarly, the growth to an advanced construction base, in 28½° LEO, is common to all options except 2A (which builds the 2.2 mw SPDA in geostationary orbit). All options use STS external tanks for the construction spine and all utilize the 150 kw SPDA.

The options drive the configuration more dramatically in high inclination LEO and geostationary orbits. The bases serving these options vary significantly from each other and from the initial/ advanced construction base. External tanks are not used; 25 kw SEPS array replaces the 150 kw SPDA and the number of modules and crew size is reduced.

COMPARATIVE EVALUATION – ENGINEERING



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COMPARATIVE EVALUATION – TOTAL SYSTEM PROGRAM COSTS

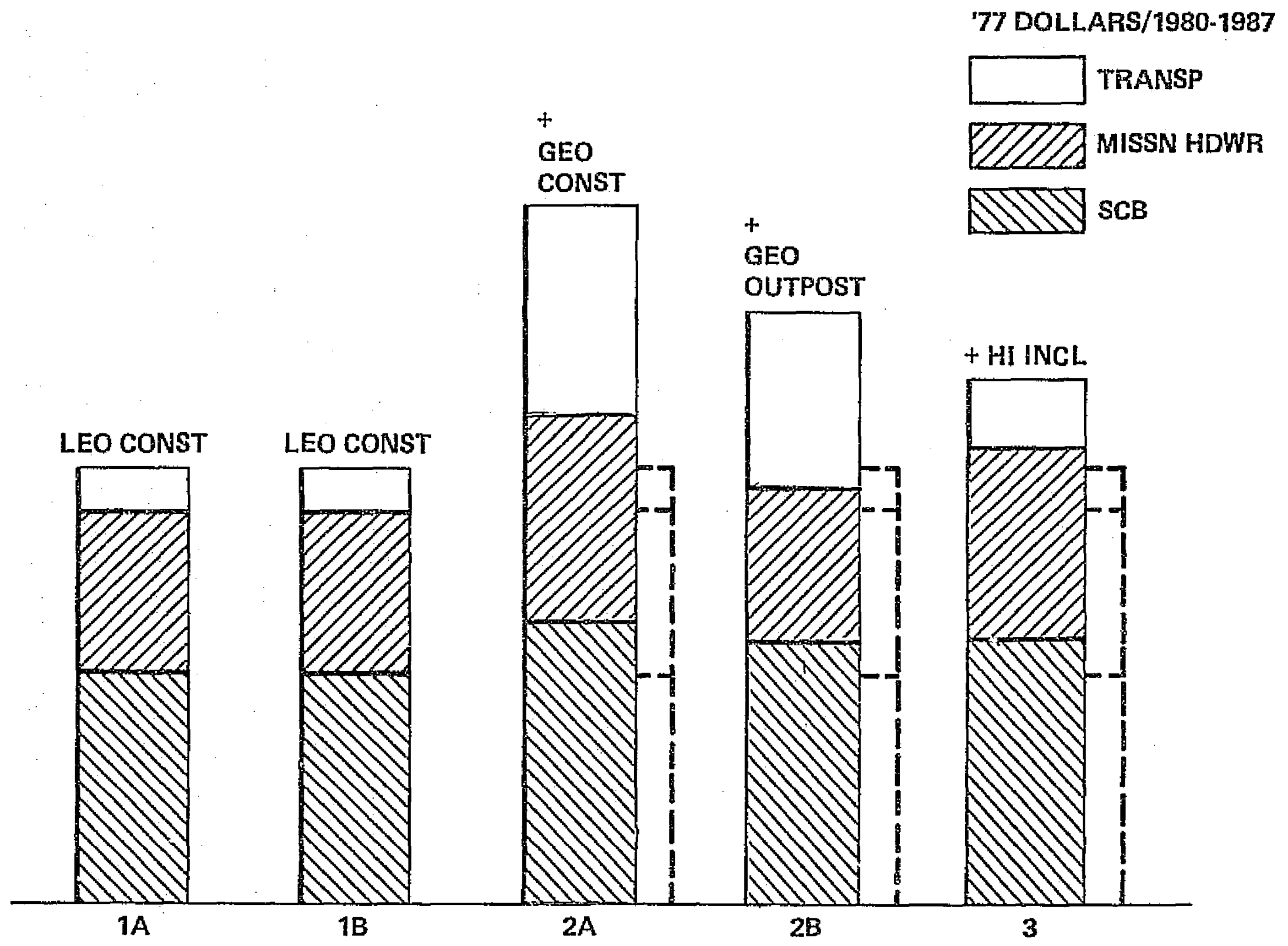
This chart examines the relative cost of each option. Costs are divided among transportation, mission hardware and space construction base. Geostationary Options 2A and 2B greatly exceed LEO Options 1A and 1B with most of the increased cost being expended for transportation.

Option 2A exceeds Options 1A/1B costs in every category: An additional base in GEOS adds SCB costs; STO experimentation adds mission hardware cost; and transportation from LEO to GEO increases transportation costs.

Option 2B has increased SCB costs due to the outpost in GEOS and increased transportation costs.

Option 3 has higher SCB costs due to the STO observatory; higher mission hardware costs due to the STO experimentation; and slightly increased transportation costs due to lower STA payload per flight to hi-inclination orbit.

COMPARATIVE EVALUATION – TOTAL SYSTEM PROGRAM COSTS



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COMPARATIVE EVALUATION – TRANSPORTATION IMPACT

This chart shows the transportation requirements necessary to support each option.

Options 1A/1B have identical requirements and are the least demanding.

Option 2A needs the greatest number of shuttle flights and OTV-P/C flights. This option also requires early development of both the OTV-P/C and the HLLV.

Option 2B uses a lesser number of shuttle flights than Option 2A but still requires early development of the OTV-P/C and HLLV.

Option 3 has the same IUS, OTV-P/C and HLLV requirements as Options 1A/1B. The number of shuttle flights (due to lesser payload capability to high inclination orbit) increases markedly.

COMPARATIVE EVALUATION – TRANSPORTATION IMPACT

▶ PRG OPTIONS	1A	1B	2A	2B	3
▶ TIME-BLOCK-(TYP)	'84-'87 | '88-'91				'84-'87 | '88-'91
▶ STS FLTS	22 | 30	22 | 30	61 | 48	39 | 36	32 | 46
▶ IUS & SEPS IOC FLTS	'84 1 | 1	'84	'84	'84	'84 1 | 1
▶ OTV-P/C IOC FLTS	'90 5	'90 5	'86 9 | 12	'86 6 | 8	'90 5
▶ HLLV IOC	'90	'90	'89	'89	'90
▶ IMPACT SUMMARY ⇨	—— MIN ——		HEAVIEST EARLY	HEAVY	HEAVY LATE

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COMPARATIVE EVALUATION – PROGRAM OPTION EFFECTIVENESS FOR SPS DEVELOPMENT MISSION

All options are equally effective in providing SPS development. The 2 mw SPDA is constructed and developed in low earth orbit and then transported to Geostationary orbit in all options except Option 2A where construction is done in GEOS.

Options 1A, 1B and 3 construct the full size SPS in low earth orbit and then transport to GEOS.

Options 2A/B construct the full size SPS in Geostationary Orbit – these options require early development of OTV-P/C and HLLV.

COMP. EVAL PROG. OPTION EFFECTIVENESS FOR SPS DEV MISSION

PRG OPTIONS TAILORED TO SUIT ALT. SPS DEV SCENARIOS EACH PRG. OPTION EQUALLY EFFECTIVE.

1A	FULL SIZE SPS CONST 100% IN LEO	• 2 MW SPDA CONST & DEV IN LEO-TRANS TO GEOS IN '88 (IUS + SEPS)
2A	FULL SIZE SPS CONST 100% IN GEOS	• 2 MW SPDA CONST & DEV IN GEOS • ADV C.B. IN GEOS
2B	FULL SIZE SPS CONST 100% IN GEOS	• 2 MW SPDA CONST & DEV IN LEO-TRANS TO GEOS IN '87 (OTVP/C) • OUTPOST IN GEOS
1B	MINOR VARIANT OF 1A - 150 KW SPDA CONST. ON SCB IN '84 - NOT WITH SORTIE FLTS IN '83	
3	PROGRAMMATIC VARIANT OF 1A - NOT AFFECTING SPS DEV.	

ALL OPTIONS EFFECTIVE

FOR SCB ALL APPROACHES EXCEPT 100% LEO CONST INVOLVE EARLY OTV-P/C IOC ETC

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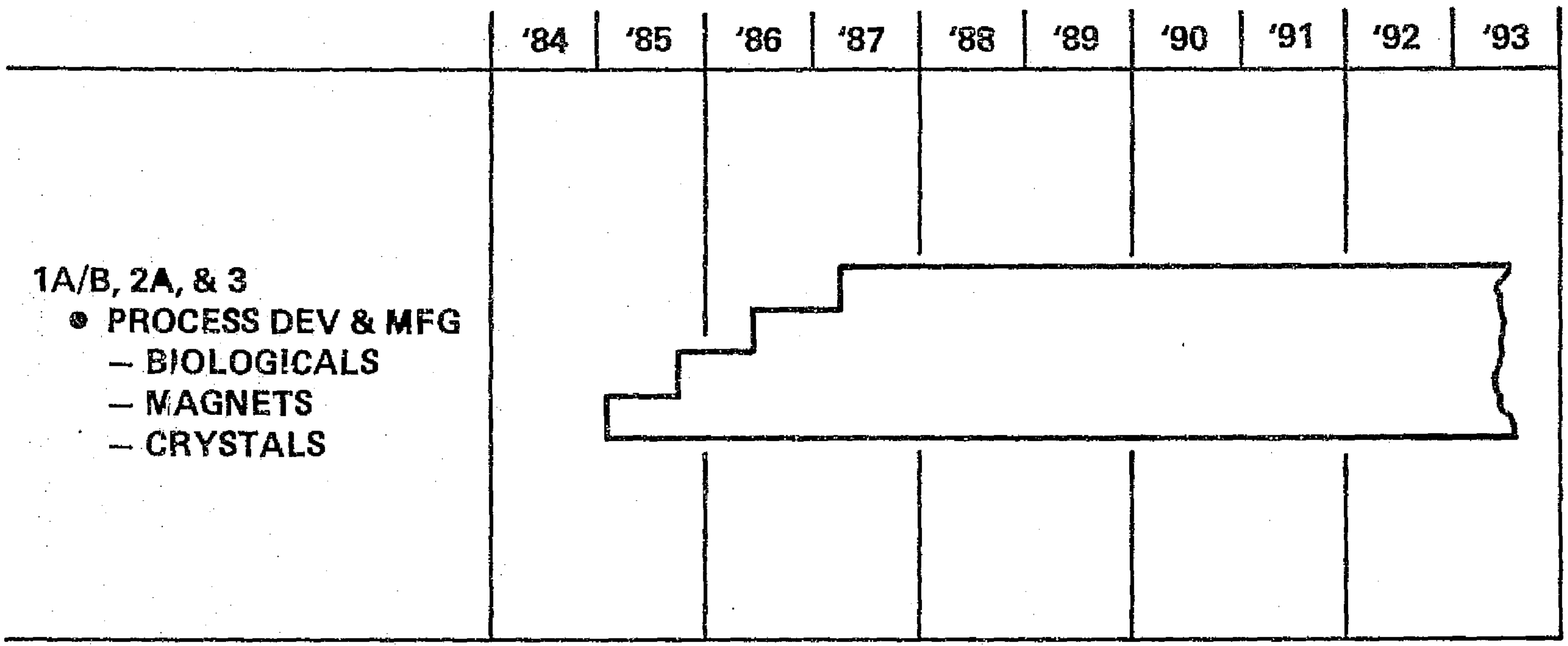
COMPARATIVE EVALUATION – PROGRAM OPTION EFFECTIVENESS FOR SPACE MANUFACTURING

All options provide space manufacturing testing, development, and production on the same schedule. All space manufacturing is performed in low earth orbit.

COMP EVAL PRG OPTION EFFECTIVENESS FOR SPACE MFG

ALL OPTIONS EFFECTIVE



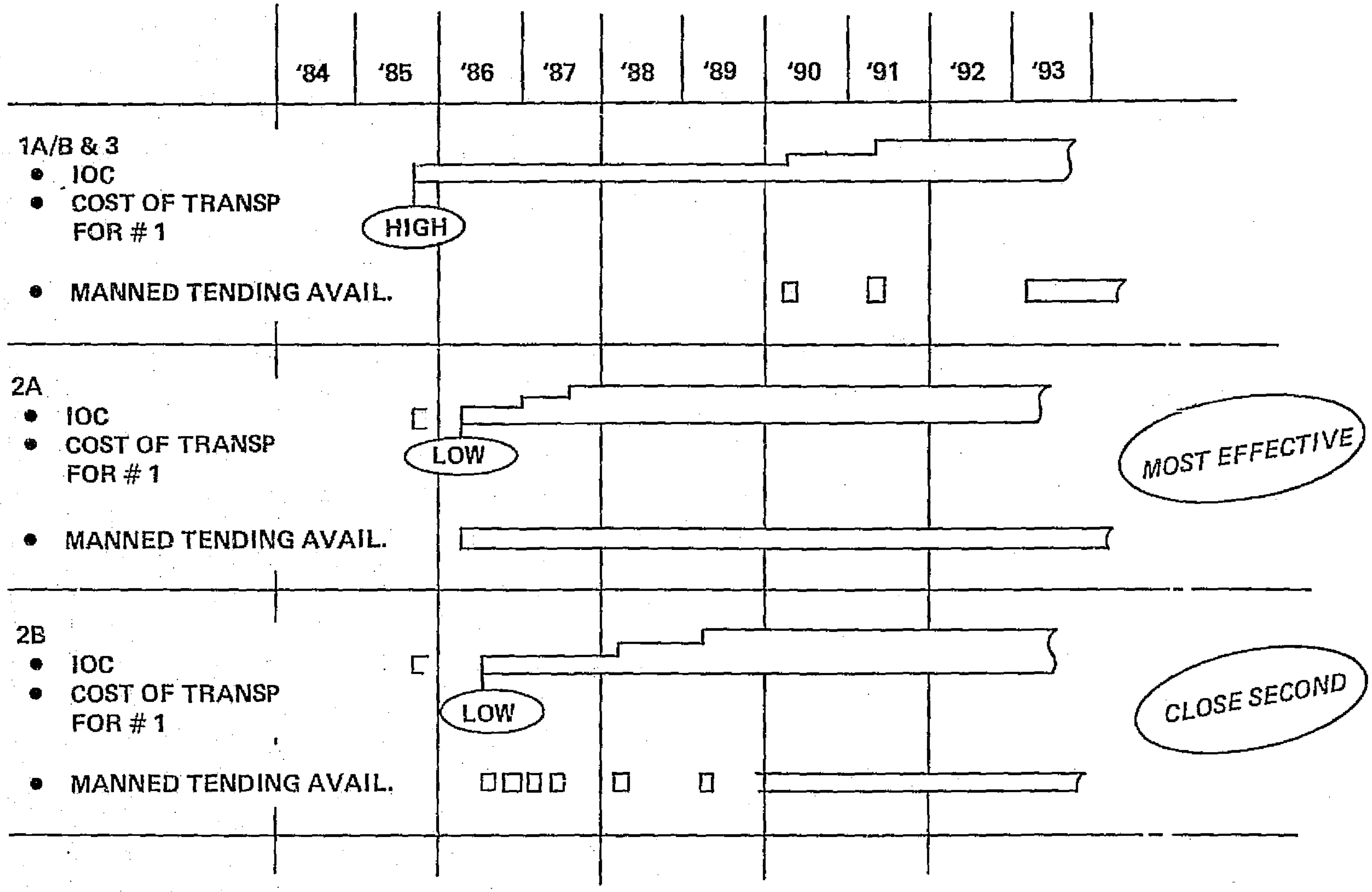
COMPARATIVE EVALUATION — PROGRAM OPTION EFFECTIVENESS FOR PUBLIC SERVICE PLATFORM MISSION

All PSP's operate from geostationary orbit. There are three PSP's in each option: PSP No. 1-Voice/Data; PSP No. 2-Video/Data; and PSP No. 3-Detection/Control.

These three PSP antennas are eventually grouped together to provide an integrated public service platform.

The schedule for the PSP IOC's for each option are shown in this chart. Option 2A has all three PSP's in geostationary orbit and operating in 1987; Option 2B accomplishes it in early 1989. All other options delay full PSP operation till 1991. The availability of men to tend the PSP's also favors Option 2A with Option 2B also offering good early service via sortie flights. The remaining options do not provide man tending capability until 1990.

COMP EVAL PRG OPTION EFFECTIVNESS FOR PSP MISSION



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COMPARATIVE EVALUATION – PROGRAM OPTION EFFECTIVENESS FOR SOLAR TERRESTRIAL OBSERVATION MISSION

STO experimentation includes solar, terrestrial, atmospheric and magnetospheric measuring units. As shown in the STO section of this report, all measurements except solar require LEO-high inclination (or Geostationary) orbits to be effective.

Options 1A/B (LEO-28½°) perform solar experiments satisfactorily but must rely on free flyers at higher inclinations to perform the remaining experiments.

Options 2A/B (Geostationary) perform all experiments well but require new instrumentation and/or sensors to provide acceptable data from that altitude.

Option 3 (LEO-high inclination) satisfies all requirements.

COMP EVAL PRG OPT EFFECTIVENESS FOR STO MISSION

		'84 '85 '86 '87 '88 '89 '90 '91 '92 '93
1A/B	SOLAR TERREST/ATMOS MAGNETS PH	LEO/28½° FREE FLYER → GEOS
1A/B	ALTERNATIVE	LEO SCB PLACED IN 55° ORBIT FOR ALL OBSV CATEG $500 M EXTRA TRANSP THRU '91 LEAST EFFECTIVE
2A	SOLAR TERREST/ATMOS MAGNETS PH	GEOS • NEW SENSORS REQD • GOOD COVERG 1/3 EARTH
2B		SIMILAR TO 2A BUT • IOC 6 MO LATER • NOT CONT MANNED TILL '90
3	SOLAR TERREST/ATMOS MAGNETS PH	LEO/85° $1080 M THRU '91 MOST EFFECTIVE

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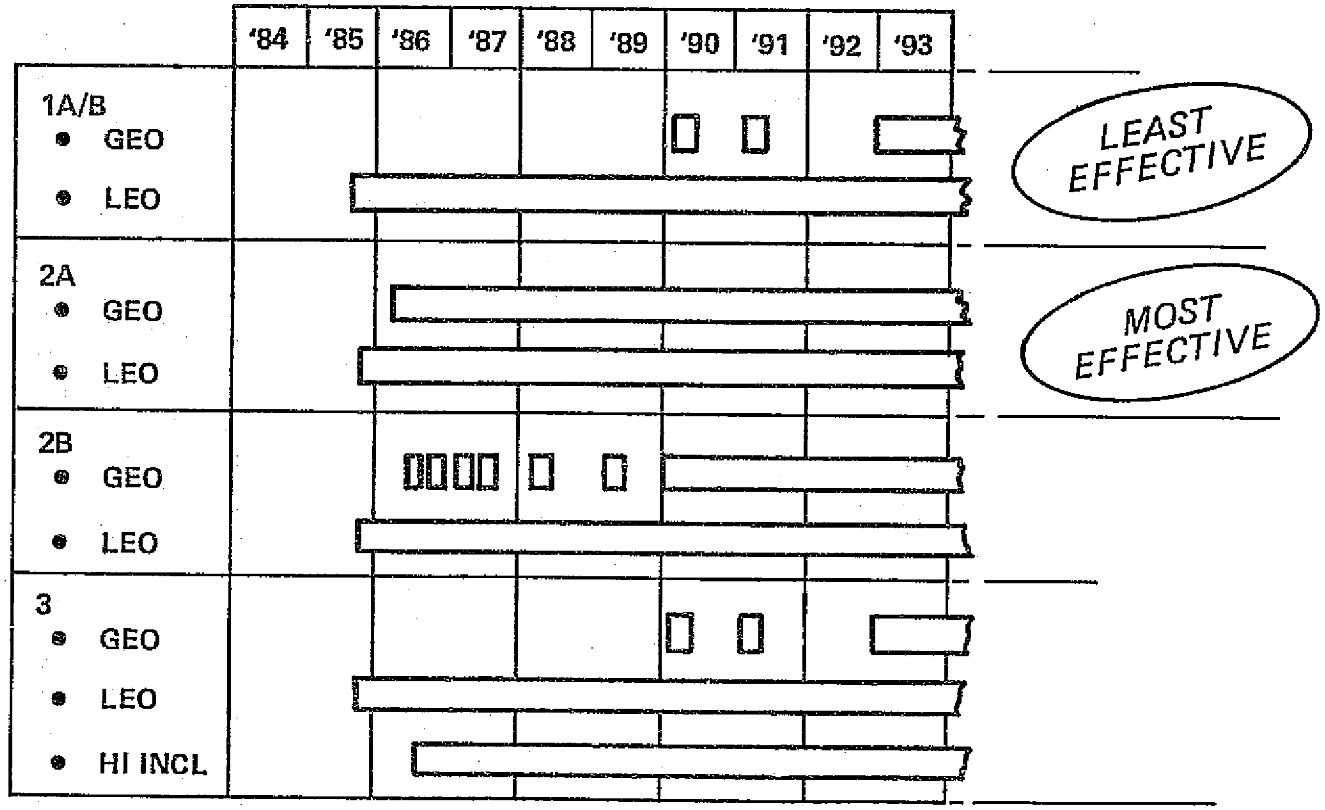
COMPARATIVE EVALUATION – PROGRAM OPTION EFFECTIVENESS FOR LIFE SCIENCE MISSION

LEO earth science data is available from all options on the same schedule. Geostationary orbit data will be abailable first from Option 2A.

Option 3 will provide life science information from high inclination low earth orbit.

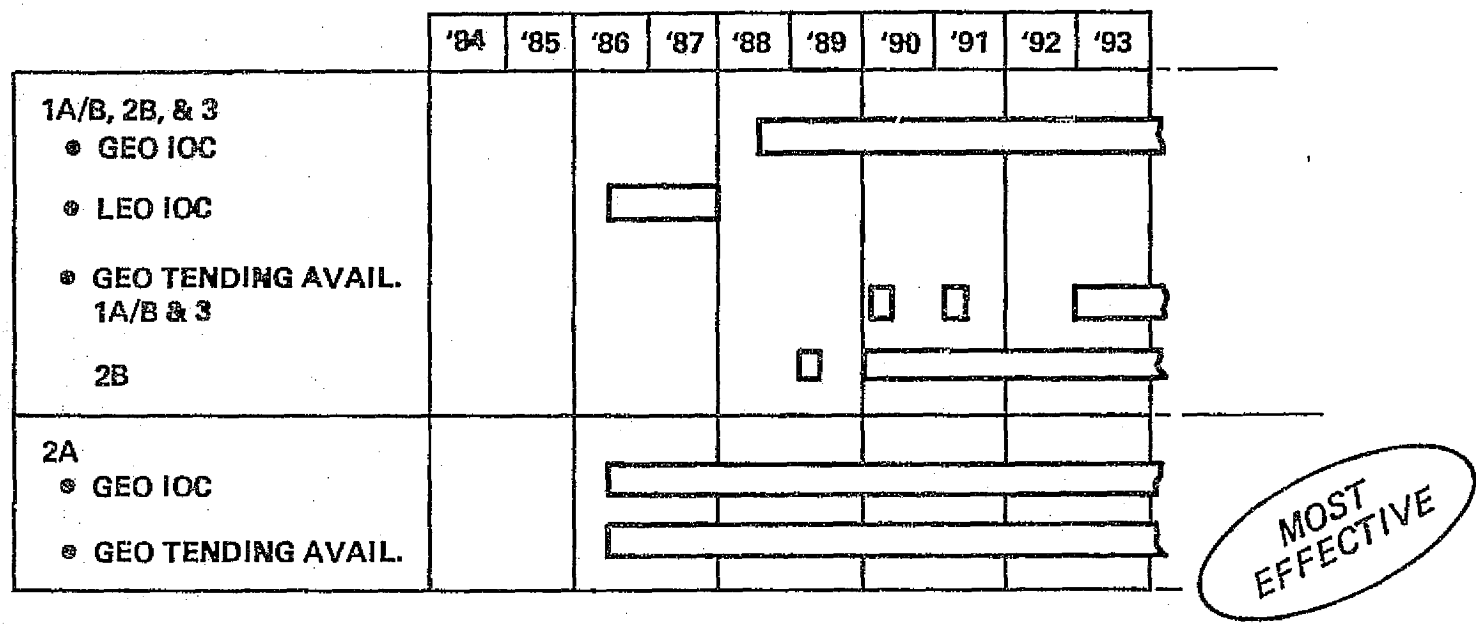
COMP EVAL PRG OPTION EFFECTIVENESS FOR LIFE SCIENCE MISSION



COMPARATIVE EVALUATION – PROGRAM OPTION EFFECTIVENESS FOR RADIO ASTRONOMY

The radio astronomy experiment will be "bootlegged" on the back side of the 2.2 mw SPDA. Option 2A will provide data from geostationary orbit starting in 1986. All other options will provide LEO data in 1986-1987 and GEOS data after transfer of the LEO built SPDA to GEOS in 1888.

COMP EVAL PRG OPTION EFFECTIVENESS FOR RADIO ASTRONOMY



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COMPARATIVE EVALUATION – TECHNOLOGY STATUS

The technological challenges for all options in LEO include the development of a crane system that provides the necessary stiffness, rigidity and versatility for a reasonable weight. Attitude control, station keeping and orbital maintenance for the changing/evolving configurations is another challenge common to all options in LEO.

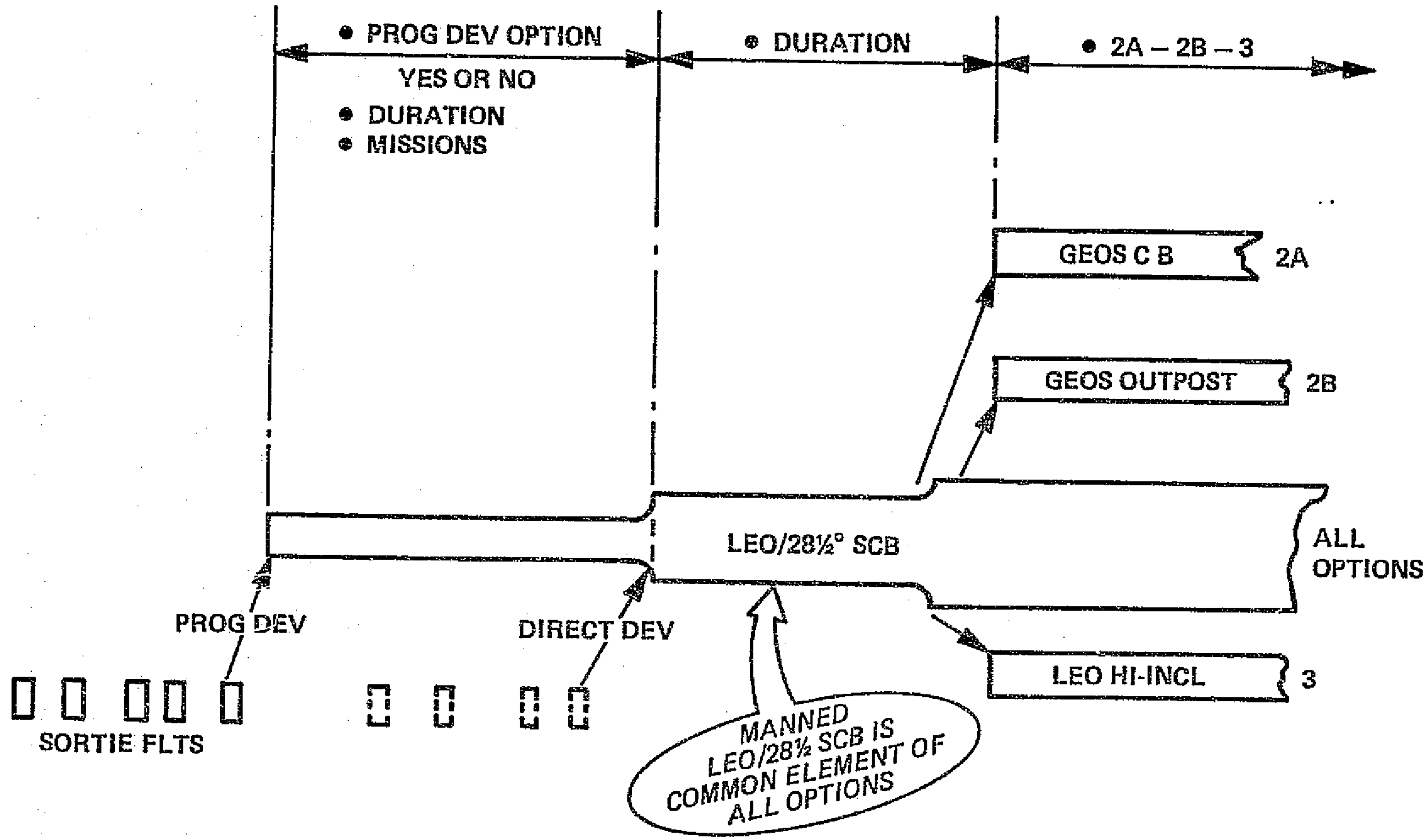
The GEOS options (2A/B) require additional technological development to provide for men living safely in this more hostile environment. The higher radiation levels require additional protection. especially during EVA. Detection, early warning and crew protection during solar storms is another problem requiring additional development in GEOS.

TECHNOLOGY STATUS

- MOST DEV NEEDED FOR GEOS
- NO SHOW STOPPERS

TECHNOLOGY DEVEL ITEMS	LEO IMPACT	GEOS IMPACT
RADIATION PROTECTION		√
SOLAR STORM EARLY WARNING		√
CRYO PROPELLANT BOIL-OFF COUNTERMEASURES		√
MANIP/CHERRY PICKER RIGIDITY/VERSATILITY	√	√
FLT CONTROL – SCB + LARGE FLEXIBLE STRUCTURE	√	

AREAS OF PROGRAMMATIC FLEXIBILITY



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COMPARATIVE EVALUATION SUMMARY (1 and 2)

The following two charts summarize the evaluation of the program options.

There is no clear cut winner. All options have significant advantages and disadvantages.

The progressive development option provides programmatic flexibility in establishing a useful step toward continuous manned SCB operations at low cost. The PDO provides a delay in manned system development that can be used effectively to meet early funding constraints. However, an extensive delay in implementing SCB manned systems development will also impact and delay SPS development and geostationary construction planning.

COMPARATIVE EVALUATION SUMMARY (1)

ENGINEERING:

- INITIAL LEO SCB SAME FOR ALL OPTIONS
- 2A/2B/3 – ENG. CHANGES FOR OTHER ORBITS MINIMIZED BY POTENTIAL MODULE & SUBSYSTEM COMMONALITY

COST:

- PROG DEVELOPMENT OPTION – LOW COST START
- INITIAL LEO SCB – SIGNIFICANT $
- 2A/2B/3 – COST MORE. 2A & 2B MOSTLY DUE TO TRANSPORT

TRANSPORT:

- 2A —— HEAVIEST IMPACT/EARLY
- 2B —— HEAVY IMPACT
- 3 —— HEAVY IMPACT/LATE

BUDGET:

- PDO WITH A TWO-YEAR TRANSITION PHASE ALLOWS A MODEST START TO ALL OPTIONS
- 2A/2B DEMAND REQUIRES EARLY IOC'S FOR OTV - P/C HLLV, OTV - C

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COMPARATIVE EVALUATION SUMMARY (2)

MISSIONS:	SPS DEV	– EACH OPTION SERVES ITS DESIGNATED SPS DEV SCENARIO
	SPACE MFG	– ALL OPTIONS PERFORM EQUALLY
	PSP	– 2A MOST EFFECTIVE – 2B A CLOSE SECOND
	STO	– 3 MOST EFFECTIVE – 1 LEAST EFFECTIVE
	LIFE SC	– 2A MOST EFFECTIVE
	RADIO AST	– 2A MOST EFFECTIVE

TECH. STATUS: NO SHOW STOPPERS

GROWTH CAP: 2A/2B/3 CAN GROW FROM TWO POINTS

PROG FLEX: IN PROG DEV OPTION & INITIAL LEO SCB PHASE FLEXIBILITY IS SAME FOR ALL OPTIONS

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